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RADC-TR-60-94

JUNE 1960

FINAL TECHNICAL REPORT

The Development of an Experimental Model of a High-Power, Broad-Band, Coaxitron Amplifier

Prepared by:

W. N. Parker
J. J. O'Grady
Power Tube Engineering

Approved by:

B. B. Brown
J. L. Straub, II
Power Tube Engineering

RADIO CORPORATION OF AMERICA
Electron Tube Division
Industrial Tube Products
Lancaster, Pennsylvania

CONTRACT AF30(602)-1892

Prepared for:

ROME AIR DEVELOPMENT CENTER
Air Research and Development Command
United States Air Force
Griffiss Air Force Base
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FOREWORD

This Final Technical Report covers the work accomplished by the Power Tube Operations organization of the Radio Corporation of America, Lancaster, Pennsylvania, during the period 6 June 1958 and 10 February 1960, on the development of an Experimental Model of a high-power broad-band "Coaxitron amplifier as referred to in "Purchase Request Continuation Sheet For Integral Cavity Triode" dated 16 January 1958 and RCA Development Proposal DP-635, "High-Power Broad-Band Amplifier -- Development of Experimental Model" dated 2 April 1958.

This work was sponsored by the United States Air Force, Rome Air Development Center, Griffiss Air Force Base, New York, under Contract AF30(602)-1892.

ABSTRACT

This Final Technical Report describes the electrical and mechanical design and low power evaluation of an experimental model, high-power, wide-band, pulsed-amplifier tube with integrated radio frequency circuitry.

This experimental model, produced during this program, has demonstrated encouraging performance during its provisional evaluation. The design objectives of 25 microsecond pulse width, 0.01 minimum duty factor and 30% minimum efficiency are well within the capabilities of the tube. The design power output of 5 megawatts could not be confirmed because the available drive power was insufficient. The bandwidth, which was designed to be 80 megacycles, measured about 70 megacycles. The design frequency band of 385 megacycles to 465 megacycles had shifted downward about 4.5%. During provisional evaluation, the tube was operated at a power output of over 1.5 megawatts at efficiencies as high as 45%. The data collected and analyzed during this provisional evaluation indicates that all of the design objectives can be met with continued development.

Contract AF30(602)-1892
Final Report

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GENERAL INTRODUCTION

This report covers the work accomplished by the Power Tube Operations organization of the Radio Corporation of America, Lancaster, Pennsylvania on the development of an Experimental Model of a high-power broad-band "Coaxitron" amplifier as referred to in "Purchase Request Continuation Sheet For Integral Cavity Triode" dated 16 January 1958 and RCA Development Proposal DP-635 "High-Power BroadBand Amplifier -- Development of Experimental Model" dated 2 April 1958.

This work was sponsored by the United States Air Force, Rome Air Development Center, Griffiss Air Force Base, New York, under Contract AF30(602)-1892.

SECTION II

SUMMARY

This report describes the electrical and mechanical design and low power evaluation of an experimental model high-power wide band pulsed amplifier tube with integrated radio frequency circuitry having design objectives as discussed below.

This Experimental Model has demonstrated encouraging performance during its provisional evaluation. The design objectives of 25 microsecond pulse width, 0.01 minimum duty factor and 30% minimum efficiency are well within the capabilities of the tube. The design power output of 5 megawatts could not be confirmed because the available drive power was insufficient. The bandwidth, which was designed to be 80 megacycles, measured about 70 megacycles. The design frequency band of 385 megacycles to 465 megacycles had shifted downward about 4.5%. During provisional evaluation, the tube was operated at a power output of over 1.5 megawatts at efficiencies as high as 45%. The data collected and analyzed during this provisional evaluation indicates that all of the design objectives can be met with continued development.

SECTION III

INTRODUCTION

The contract for this developmental program calls for furnishing one Experimental Model of a high-power, wide-band, pulsed amplifier tube with integrated radio frequency circuitry, having the following design objectives:

A. Frequency: The tube shall be capable of operation in the frequency range of 385 to 465 megacycles per second minimum.

B. Bandwidth: 80 megacycles minimum at the 3.0 decibel power points from a center frequency of 425 megacycles.

C. Power Output: 5 megawatts minimum into a load having a voltage standing wave ratio of not greater than 1.1:1. The contractor shall strive as an objective to maintain the peak power constant over the range of frequencies specified.

D. Pulse width: 25 microseconds minimum.

E. Duty Factor: 0.01 minimum.

F. Efficiency: 30 percent minimum when operated under power output conditions specified in C.

G. Power gain: A maximum consistent with the electrical design of the tube.

H. Cathode: The cathode shall be a matrix-oxide type.

I. Cooling: In order to provide adequate cooling of the tube, suitable coolant courses through the tube elements with accessible connectors shall be provided.

J. Load Voltage Standing Wave Ratio (VSWR): The tube shall be designed for operation into a load having a VSWR of 1.5:1 for all phases without evidence of operational instability.

In addition, RCA has conducted evaluation tests of the Experimental Model Coaxitron at moderate power levels.

SECTION IV

THE EXPERIMENTAL MODEL COAXITRON AND PROVISIONAL EVALUATION

The name Coaxitron, derived from the coaxial nature of the structure, has been given to define integral-circuit, grid-controlled amplifier tubes. Two Coaxitrons were built during the course of this experiment. Model A, an interim version, was used to establish some of the basic design and processing concepts prior to the completion of Model B. This was the first Coaxitron Model completed with the integral band-pass radio frequency output circuitry and grid-controlled electronic structure combined within a vacuum envelope.

Figure 1 is a photograph of the Model B Coaxitron. The larger diameter at the bottom encloses the anode, grid-controlled electronic structure and most of the integral rf circuitry. The grid-controlled electronic structure is similar to that of the RCA Developmental Tube Type A-2346, a 5 megawatt triode. The voltage sampling probes around the periphery, which would be included only on early developmental models, permit examination of the rf voltage distribution within certain portions of the vacuum circuitry. The long, smaller diameter stack encloses the auxiliary output cavity and coaxial output line. The ceramic cylinder at the center of the stack is the output vacuum window for coupling rf energy directly to the output waveguide.

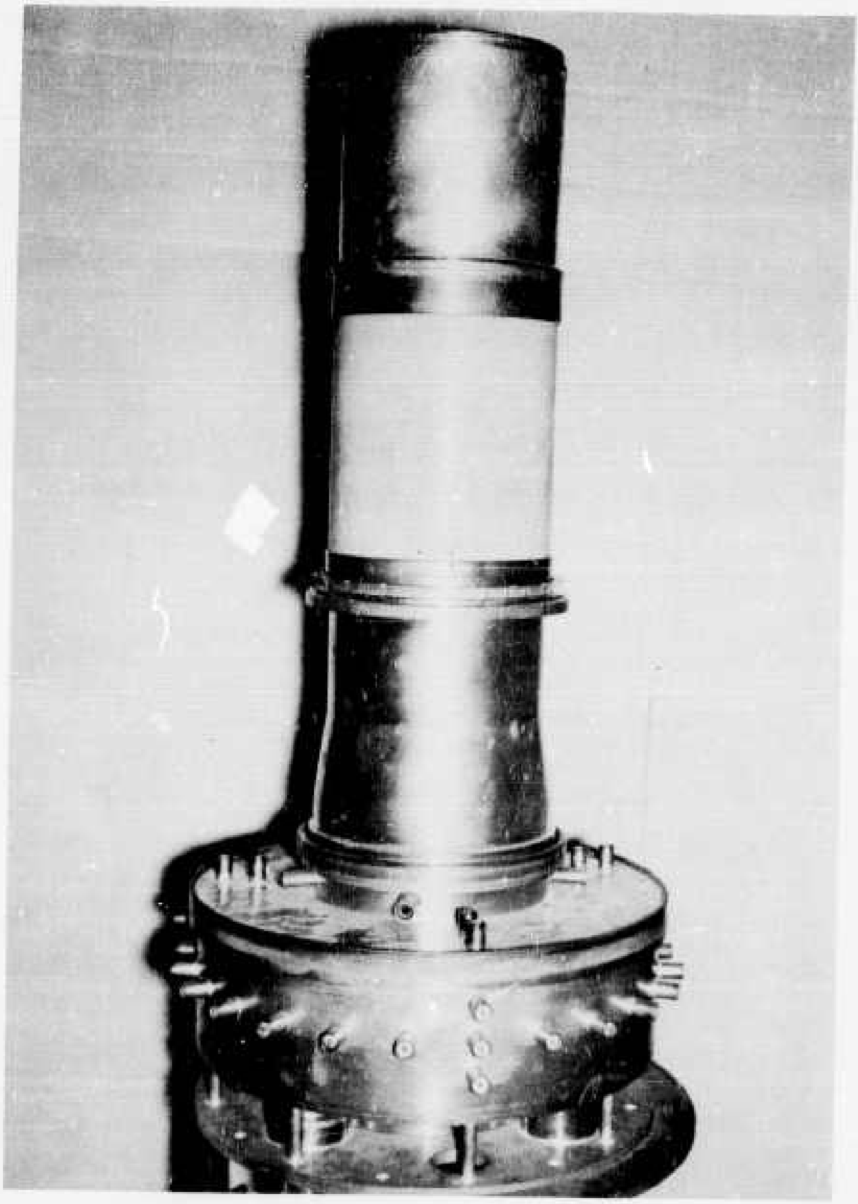

Figure 1 -- The Model B Coaxitron: The Larger Diameter at the Bottom Encloses the Anode, Grid Controlled Electronic Structure, and Most of the Rf Circuitry. The Small Cylinders Around the Periphery are the Voltage Sampling Probes. The Long Smaller Diameter Stack Encloses the Auxiliary Output Cavity and Coaxial Output Line. The Ceramic Cylinder at the Center of the Stack is the Output Vacuum Window for Coupling Rf Energy Directly to the Output Waveguide.

A typical test set-up for the Coaxitron is shown in the photograph of Figure 2. It can be easily seen that the tube merely inserts into a waveguide, one portion of which transmits the rf energy to the load while the other portion, which is shown to the right of the Coaxitron in the photograph, contains a waveguide shorting plunger which is mechanically fixed in one position over the entire frequency band. It is important to note that this arrangement provides a stray radiation free environment around the output circuitry.

Beneath the Coaxitron is the detachable input circuit, the filament power leads, the plate supply lead and various coolant connectors. A three inch coaxial transmission line from the rf driver is attached to the input circuit.

Provisional tests on this Coaxitron (Figures 1 and 2) have demonstrated a power output of over 1.5 megawatts with a wide band of approximately 70 megacycles at efficiencies as high as 45%. In addition, the tests have demonstrated; a potential power output capability of 5 megawatts, that a grounded-grid amplifier can have a good power gain, that there are no parasitic oscillation troubles, and that integral circuited tubes show an order of magnitude power-bandw[illegible]ct improvement over conventional external circuitry, based on [illegible]nce with nine different cavities designed for the A-2346 tube by several different engineering groups at RCA and other customers.

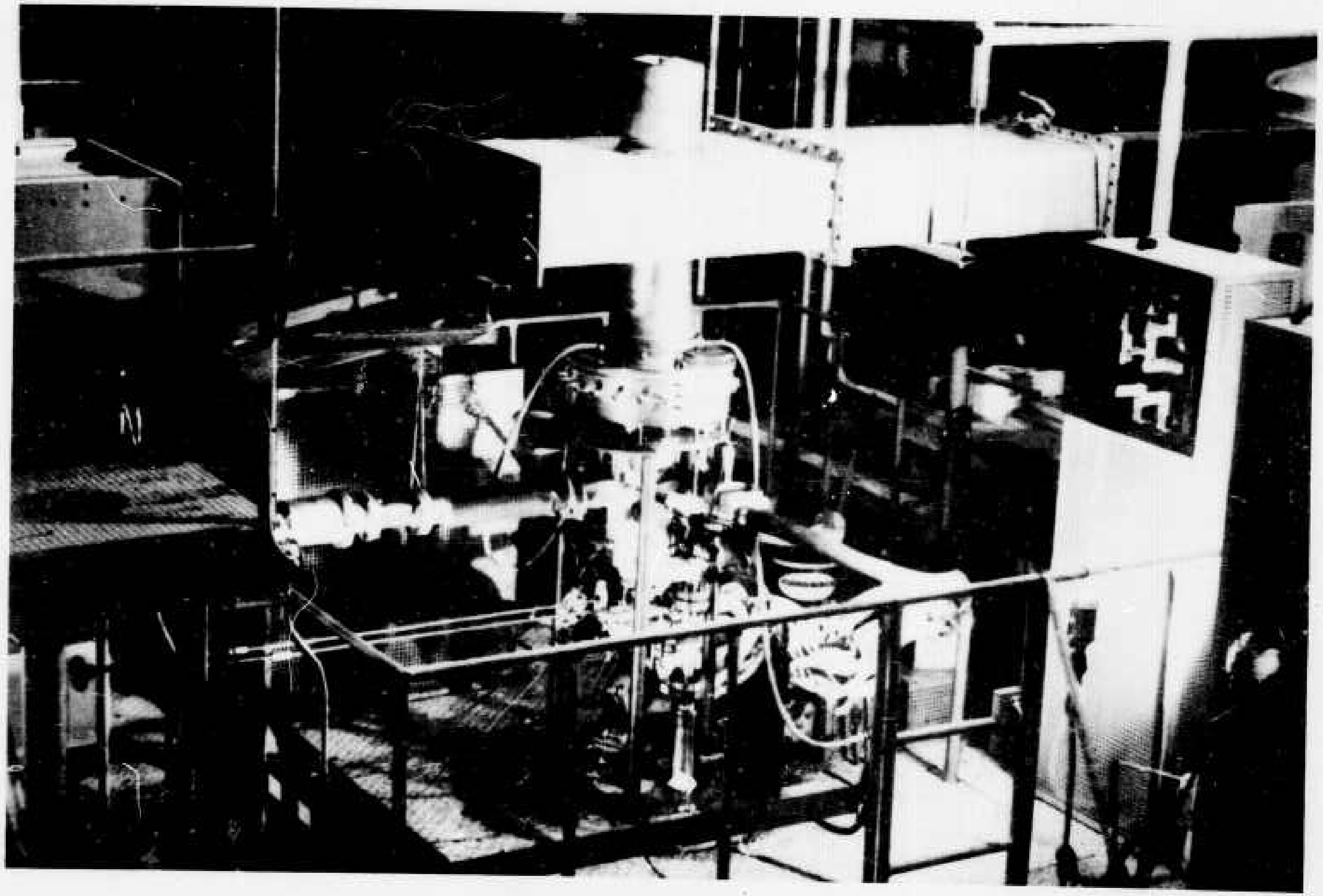

Figure 2 -- Test Set-up of the Model B Coaxitron Showing the Output Waveguide, Detachable Input Circuit, and Coaxial Transmission Line from the Rf Driver in Place.

The provisional testing of the Coaxitron utilized a dc plate supply containing electronic "crowbar" fault protection circuitry so that the high voltage was removed within 10 microseconds in the event of an internal tube arc. The driver supplied pulsed rf power of 10 microseconds duration. The rf output power was measured calorimetrically using a UHF water load. A panoramic search receiver was used to explore for spurious outputs and parasitic oscillations. A VacIon* Pump was attached to the tube to clean up gas evolved during aging and to provide continuous monitoring of the gas pressure.

*Varian Associates, Palo Alto, California

SECTION V

CONSTRUCTIONAL FEATURES OF THE EXPERIMENTAL MODEL COAXITRON

A simplified longitudinal cross-section of the Coaxitron is shown in Figure 3.

Electron emission is supplied by 96 directly heated, ribbon-type filamentary cathode strands. The cathode emissive surface consists of a matrix of finely divided nickel powder sintered to the ribbon base and saturated with barium and strontium oxides. Long life emission can be expected from these cathodes because their capability is at least twice that required by the intended service. Each cathode strand is mounted by a pantographic tensioning device which compensates for thermal expansion and assures precise grid-to-cathode spacing. This method of cathode support has had over 10 years of proven success in RCA super power tubes.

The grid structure is coaxial with the cathode array and consists of two fine-pitched concentric helices of fine tungsten wire embedded in 96 copper supporting fins extending radially outward between the individual cathodes. Adequate coolant flow in the grid block effectively cools the grids via the supporting fins thereby assuring the maintenance of accurate electrode spacings.

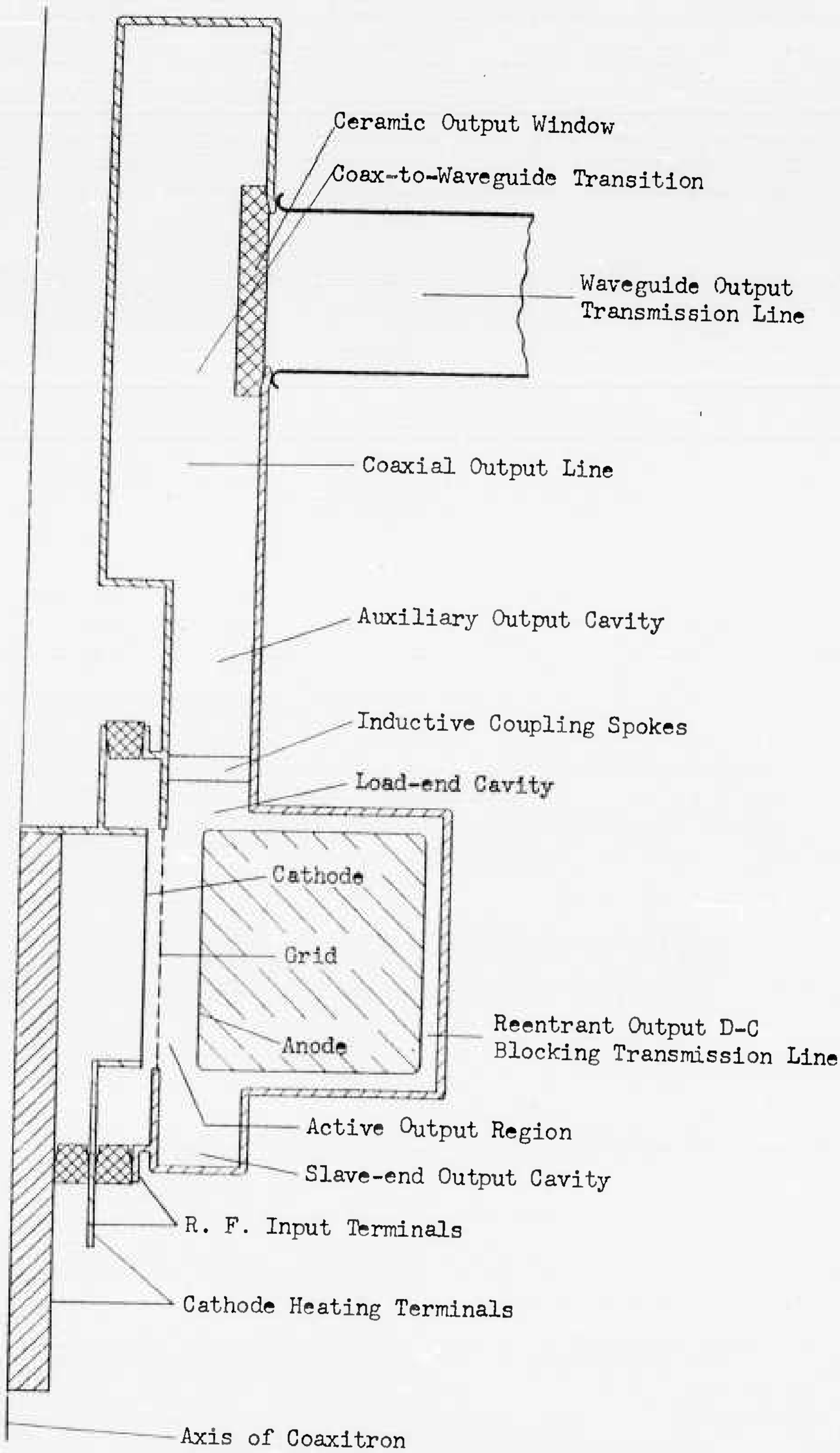

Figure 3 -- Simplified Cross-Section Diagram of the Model B Coaxitron Showing the Vacuum Enclosed Output Circuitry.

The anode is outside the grid structure and coaxial with it. It is constructed of copper for good thermal conductivity and is liquid cooled by passing coolant thru channels in the back wall.

The construction of the electronic structure is shown in the axial cross section of Figure 4.

Modulation of the electron stream is accomplished by an rf drive voltage applied between the grid and cathode rf input terminals of a detachable, tunable input circuit. A relatively uniform rf voltage distribution along the length of the grid-cathode region is maintained by a fixed cavity at the end opposite the rf input terminals. RCA has had extensive experience with this structure in the A-2346 Refinement Program (BMEWS Contract AF04(647)-179 from the Air Force). This experience has demonstrated the practicality of fabricating a structure of this sort. It has shown that this structure has an extremely high cutoff mu, thereby permitting zero bias, Class B operation, which considerably enhances the stability by increased screening between the input and output circuits. Furthermore, the double grid structure has caused no great increase in electron interception by the grids.

The output circuit includes the load end cavity, the active grid-anode region, and the slave-end output cavity, all designed so that the output circuit operates in a half-wave coaxial mode. By suitably porportioning

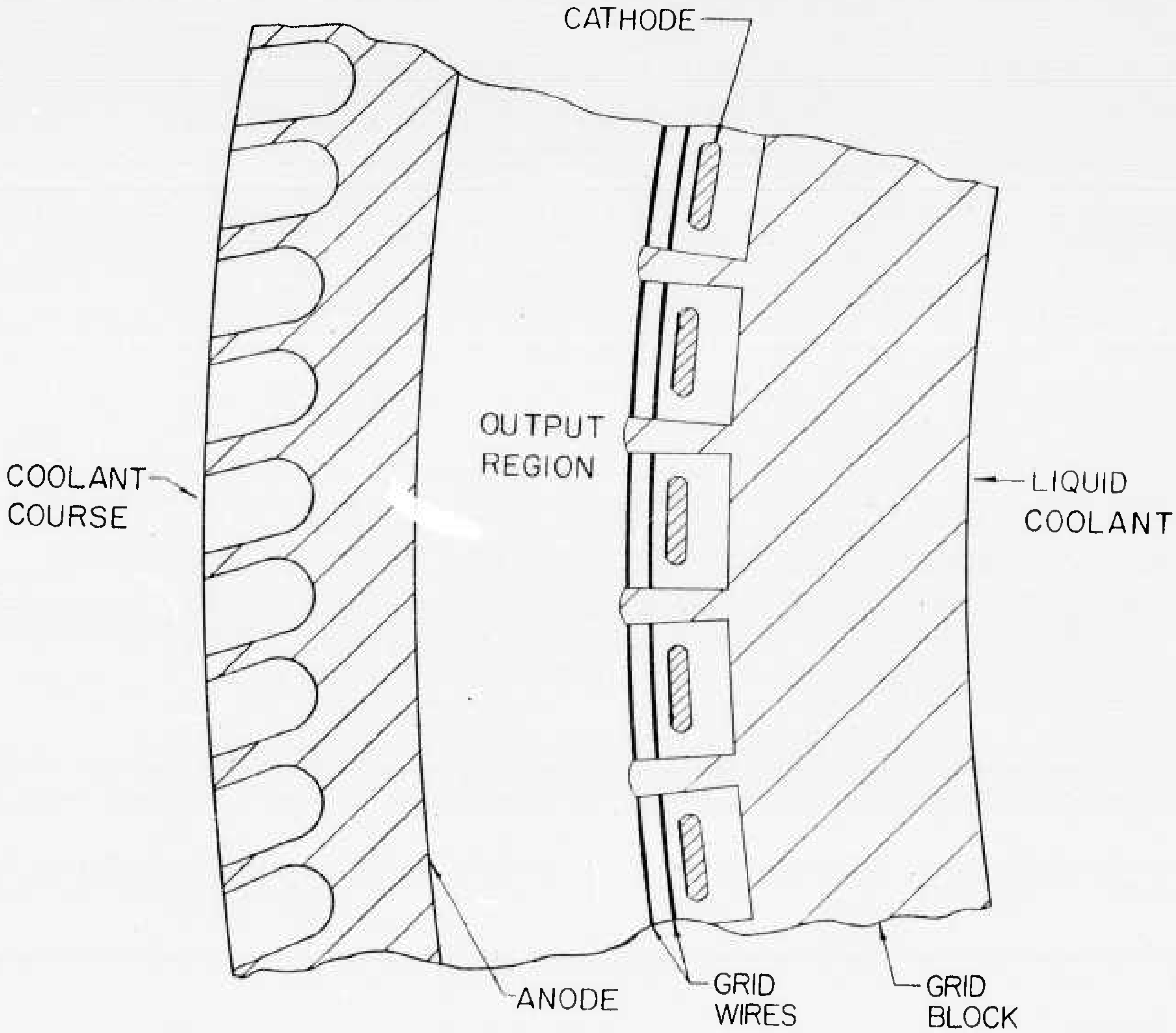

Figure 4 -- Axial Cross-Section of the Electronic Structure of the Model B Coaxitron

the slave-end output circuit, a voltage maximum can be made to occur at the mid-plane along the length of the grid-anode region.

A re-entrant output dc blocking transmission line (commonly referred to as a blocker), which eliminates the need for an external rf output blocking capacitor, greatly simplifies the output coupling structure. It is formed between the ring-like anode block and the external metal enclosure and is electrically a half-wave long. Because it is entirely enclosed, it is completely non-radiating. The high voltage components are vacuum insulated from the external metal enclosure making the device self-healing in the event of a flashover. Since the re-entrant blocker actually transmits rf power from the slave-end output cavity, the VSWR is relatively low. Consequently, the blocker introduces little narrowing of the bandwidth. Also, the re-entrant blocker introduces no objectionable modes within the operating frequency range.

The voltage distribution along the blocking transmission line was predicted by using a 1 Mc analogue made up of tapped coaxial cable corresponding to a pie-slice section of the actual Coaxitron. The voltage distribution was later verified during cold-test adjustment of a full scale model by using the built-in voltage test probes.

The five inductive coupling spokes couple rf power symmetrically out of the load end cavity to the auxiliary output cavity. These rugged copper tubes

are proportioned and located axially to give the desired band-pass response. Their final adjustment was made during a cold-test of a full scale model, after which the tubes were brazed solidly across the load end cavity.

The auxiliary output cavity is simply an extension of the coaxial line forming the load-end cavity and has an electrical length of approximately one-quarter wave length. This auxiliary output circuit is proportioned to give the proper band-pass response into the 100 ohm load presented by the coaxial output line in conjunction with the previously discussed output circuitry. The auxiliary output circuit was finally adjusted during a cold-test of a full scale model by adding plates of various thicknesses to the end of the inner coaxial connector. The inner and outer conductors of this auxiliary output circuit are actually portions of cones which intersect each other on the axis so that uniform surge impedance is maintained. This construction is shown in the detailed cross-sectional drawing of Figure 5.

The coaxial output line, as shown on the simplified cross-sectional view of Figure 3, has a surge impedance of 100 ohms. The residual VSWR of this coaxial line is determined by the design of the coax-to-waveguide transition. As can be seen from the Smith Chart of Figure 6, it is about 1.2. The length of the coaxial line is chosen so that this residual VSWR is compensated for in part by the discontinuity capacitance at the junction with the

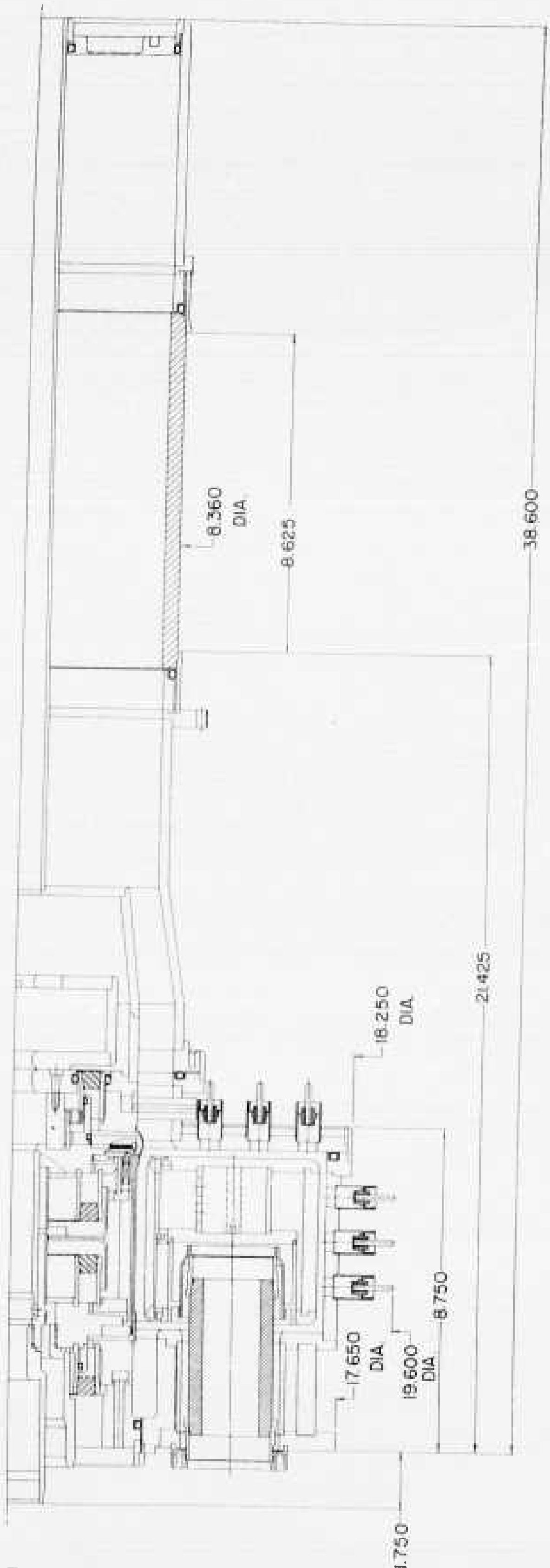

Figure 5 -- Detailed Cross-Section of the Model B Coaxitron

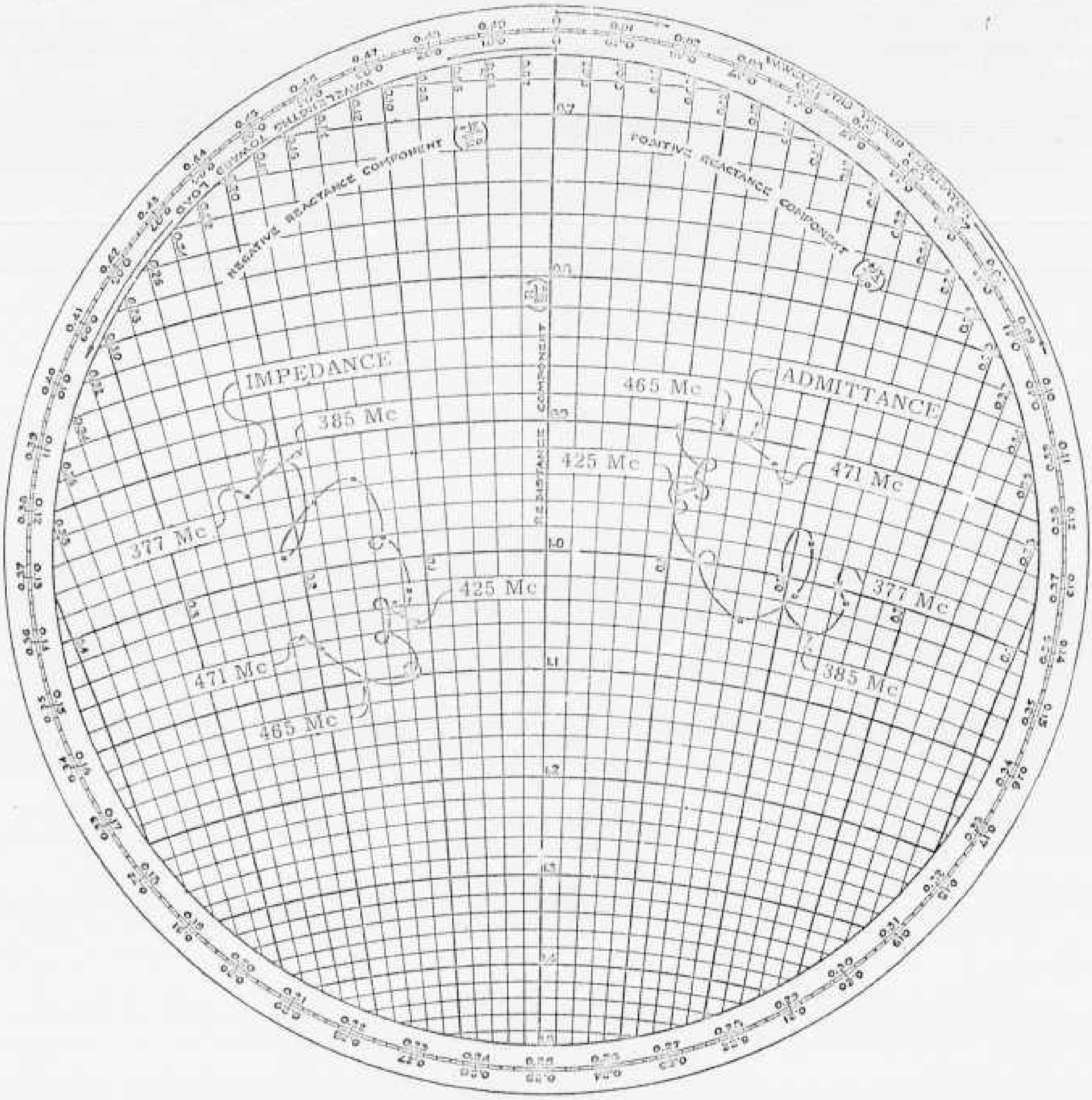

Figure 6 -- Normalized Impedance and Admittance vs. Frequency for the Model B Coaxitron Coaxial-to-Waveguide Transition.

auxiliary output cavity. The line extends through the waveguide a predetermined distance to form the coaxial tuning stub portion of the coax-to-waveguide transition.

The coax-to-waveguide transition was designed to fit 3/4 standard height WR2300 waveguide (8.625" x 23.0" inside dimensions). This design has wide spacings for high-power and also has good wide-band performance characteristics, as shown in Figure 6, when compensated as discussed above. The transition had to be designed empirically because of the presence of the ceramic output window. The design procedure consisted mainly of determining the optimum fixed length of the coaxial tuning stub and the position of the shorting plunger in the waveguide. To facilitate fabrication and rf measuring, scale models were used operating at about seven times normal frequency. Again, however, the design was checked by cold-testing a full scale model using a specially built coaxial line and low-power waveguide load.

The ceramic output window is similar to those used extensively in RCA super power tubes and uses Almanox type 4462 cylinder. This ceramic output window is joined to its metal envelope with radial compression seals.

Two similar but smaller ceramic cylinders support the anode block as can be seen by studying the detailed cross-sectional drawing of Figure 5.

These ceramic cylinders also conduct coolant from outside metallic fittings to the actual anode coolant passages. A rod-like lead (not shown on the drawing) on the axis of one of the ceramic cylinders connects the anode to the plate supply voltage.

The various major assemblies of the Coaxitron are joined by a series of inert gas welds made by techniques carefully developed from experience with super power tubes and large ultra-high-vacuum systems. Such welds can be cut apart should it become desirable to modify or replace components inside the vacuum envelope of the Coaxitron. Closely wound coil spring "rf gaskets" at the welds provide low-loss paths for rf circulating currents.

SECTION IV

PROGRESS MADE TOWARD DESIGN OBJECTIVES

The experimental model Coaxitron described above represents fulfillment of the prescribed design objectives to a very substantial degree. The main exception is that the wide-band input circuit was not built into this model. There are several reasons for this. First, the number of developmental models which could be built was limited by the scope of the program. Second, the analysis of the performance of a new design is greatly facilitated by keeping the number of new features to a minimum. Third, design priority was given to the higher powered output circuitry.

Each design objective will next be discussed along with pertinent engineering information derived from provisional tests made on the Coaxitron, cold test data, engineering analysis, and experience on other programs.

Design Objective A - "The tube shall be capable of operation in the frequency range of 385 to 465 megacycles per second minimum".

The experimental Coaxitron was actually operated at 30 different frequencies extending from 385 megacycles to 453.2 megacycles with gain and stability. However, performance depreciated rapidly above 445 megacycles, so that the upper limit of practical operation is thus 4.5 percent below the objective of 465 megacycles. On the other hand, the relative response at 385 megacycles was still less than 1 decibel down, which indicated that the lower

frequency limit is well below the objective frequency of 385 megacycles. Equipment limitations prevented testing below 385 megacycles.

The measured response is indicated in Figure 7 where the ordinate (load resistance) represents the relative power output for a given rf drive level. The position of the waveguide shorting plunger was constant during the measurements and the rf power output was as high as 1.5 megawatts. A corresponding response curve based on data taken during the final cold-test of the full scale model is shown in Figure 8.

The downward shift in the frequency band is due to a combination of a number of possible second-order effects; manufacturing dimensional tolerances, measurement error in the determination of the load resistance, slow-wave effects along the grid structure, and electronic loading in the grid-anode region.

Design Objective B - Bandwidth: 80 megacycles minimum at the 3.0 decibel power points from a center frequency of 425 megacycles.

The bandwidth design objective is almost met by the band-pass output circuitry of the experimental Coaxitron. Since operation at frequencies below 385 megacycles was beyond the tuning range of the available rf driver and input circuitry, the lower frequency portion on the curve of Figure 7 could not be completed. Considering the apparent downward shift in the frequency

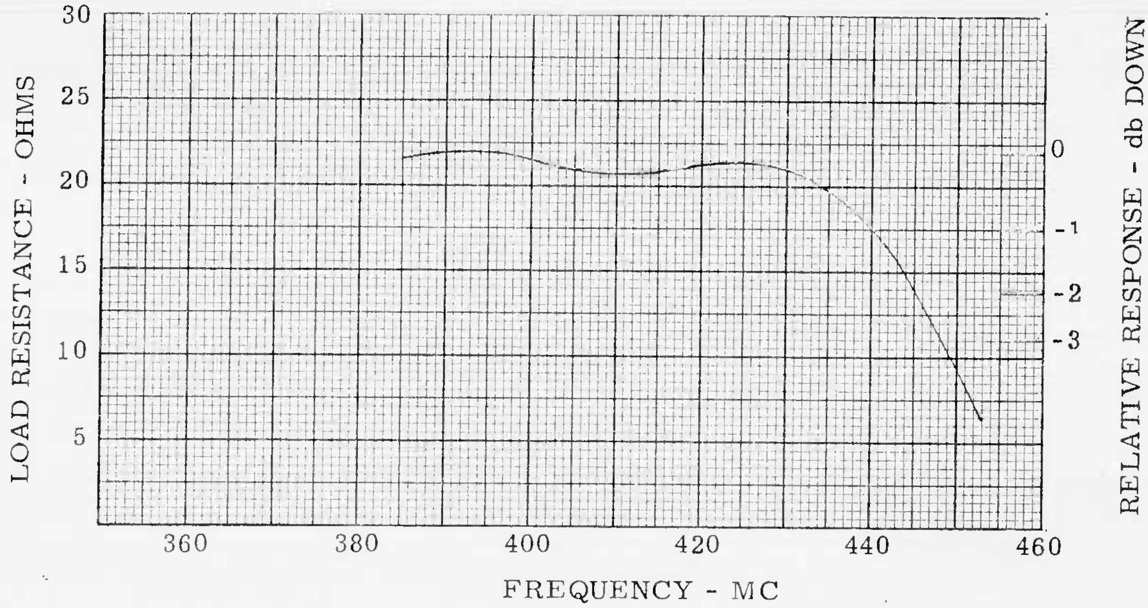

Figure 7 -- Effective Load Resistance vs Frequency as Measured during Provisional Evaluation of the Model B Coaxitron. The Relative Power Output for a Given Drive Level is Proportional to this Load Resistance. Operation at Frequencies below 385 MC was beyond the Tuning Range of the RF Driver and Detachable Input Circuit.

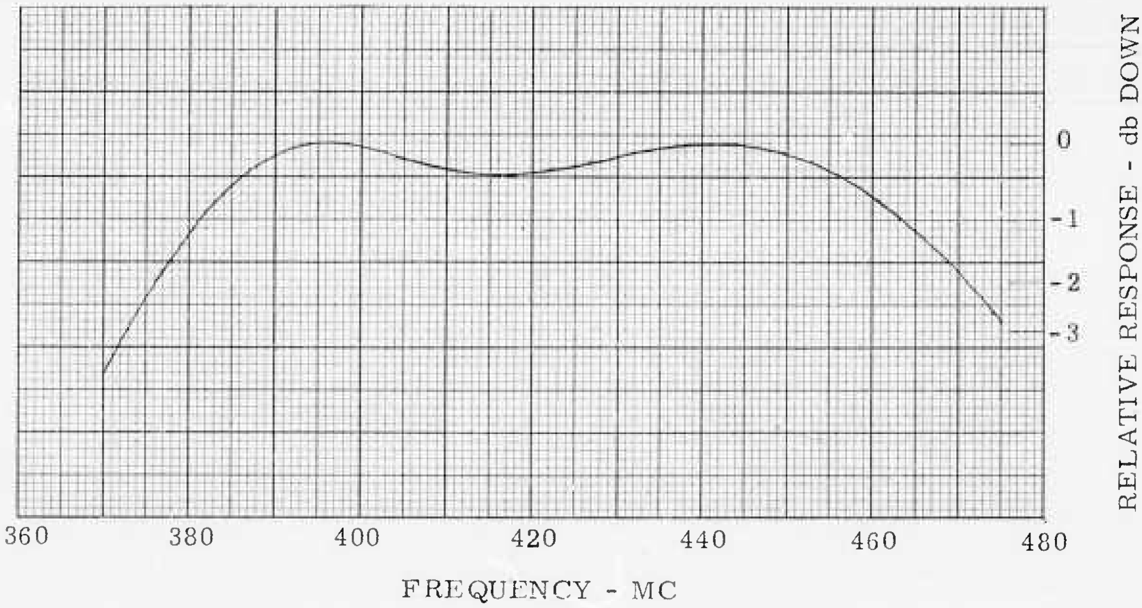

Figure 8 -- Relative Response vs Frequency as Measured during the Final Cold-Test of the Model B Coaxitron.

band and extrapolating the lower portion of Figure 7, the lower frequency at the 3.0 db point may logically be estimated at 375 Mc, which indicates a 70 Mc bandwidth. It is anticipated that the addition of the broad-band input circuitry, to be described later, will not significantly reduce this bandwidth.

Design Objective C - "Power output: 5 megawatts minimum into a load having a standing wave ratio of not greater than 1.1:1. The contractor shall strive as an objective to maintain the peak power constant over the range of frequencies specified herein."

The Experimental Model Coaxitron should be capable of 5 megawatts output. Test data taken at lower power levels may be logically extrapolated to the 5 megawatt level as shown in Figure 9. The predicted plate current would be 450 amperes which represents a conservative cathode loading of only 5 amperes per square centimeter (See Figure 18 middle curve).

The basis of Figure 9 is simply that the useful power output of any electrical device may be expressed as:

$$P_o = I^2R \tag{1}$$

where I represents the effective value of the plate current at the desired frequency, and R the effective series resistance due only to the useful load.

The maximum obtainable value of I depends chiefly upon the electron emission available per unit area of the cathode, the total cathode area, and the voltage flashover limitations in the input circuit. The effective value of I over a wide

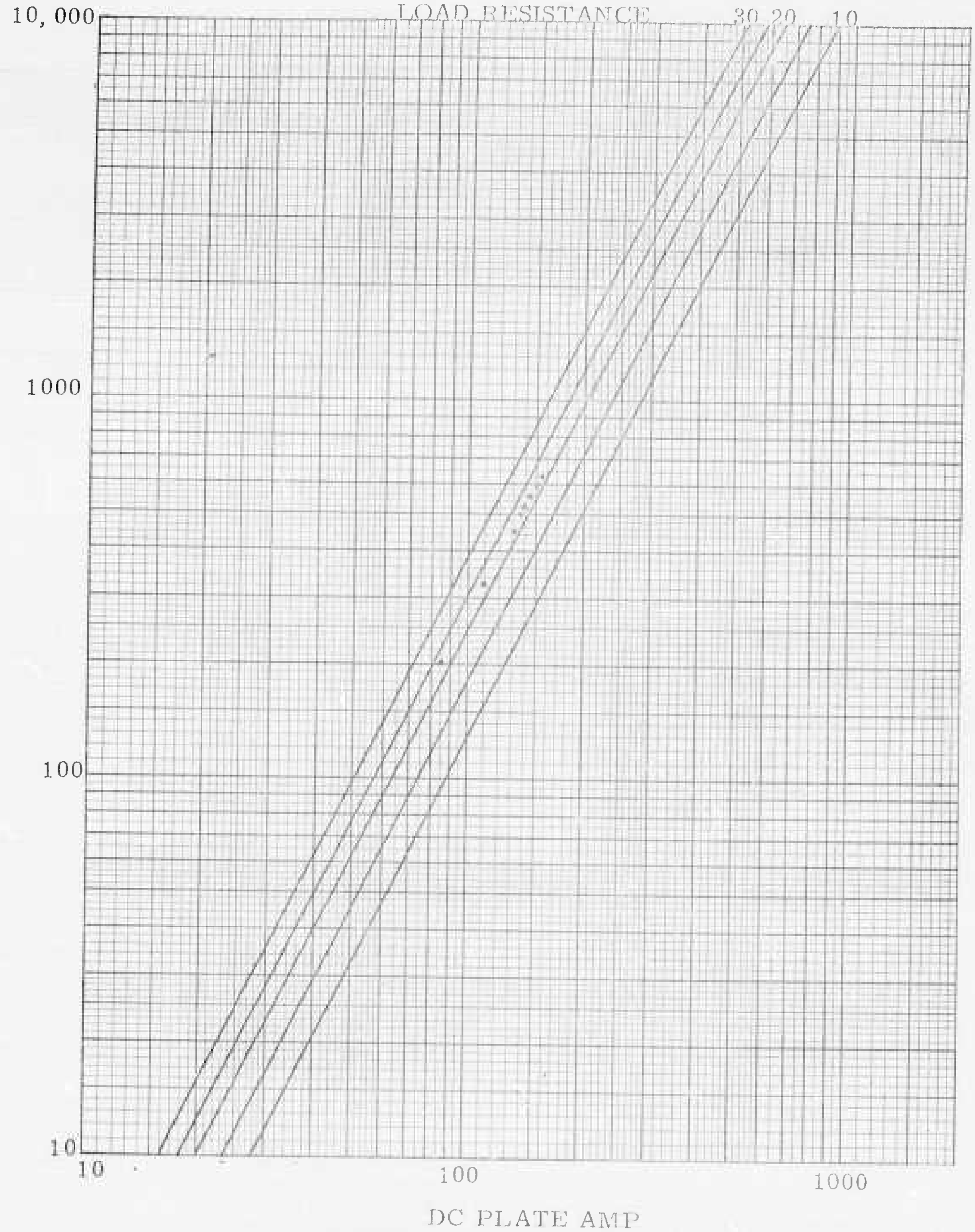

Figure 9 -- Class B Amplifier Performance: The Position of the Load Resistance Lines is set by Assuming $I_P RMS = 1.1\ I_B$ DC. The Points Plotted during Provisional Evaluation Establish a Load Resistance Line which when Extrapolated to 5,000 KW predicts a Plate Current of 450 Amperes. This Represents a Conservative Cathode Loading of only 5 Amperes per Square Centimeter.

range of operating conditions for a Class B amplifier may be assumed as approximately 1.1 times the dc plate current, I_B. The magnitude of I_B (and thus I) which is readily measurable, even during pulsed operation, depends primarily upon the peak grid-cathode drive voltage and how constant it is along the active length of the tube. Because of the Coaxitron's extremely high amplification factor, I_B should be almost independent of the plate-grid voltage.

R, which depends almost entirely upon the output circuitry, will be constant over a wide range of power levels. It can be determined at a relatively low power level by measuring P_o and I_B and using the derived equation.

$$R = \frac{P_o}{1.21\, I_B^2} \qquad (2)$$

The effective load resistance R determined in this manner from data taken during provisional evaluation is relatively constant over the frequency band as shown in Figure 7. Consequently, the portion of Objective C. "to maintain the peak power constant over the range of frequencies specified herein" is essentially attained.

Power-Bandwidth Product - The power-bandwidth product is a commonly used figure-of-merit for broadband amplifiers. As can be seen from Equation 1, the power-bandwidth product depends upon the product R times the bandwidth if I_B remains constant. An analysis of the data contained in

Figure 7 indicates that the power-bandwidth of the Coaxitron is unusually high. Whereas the R x BW for the typical external circuitry of the RCA Developmental A-2346 tube type ranges from 50 to 165 ohm-Mc, the Coaxitron has a R x BW product of 1760 ohm-Mc. Thus, the power-bandwidth product is greatly enhanced by carefully designed output cavities integral with the active electronic structure of the amplifier.

The design procedure used for the Coaxitron will next be described briefly.

Output Band-Pass Circuit Design

The three principal functions of a broadband output circuit are:

1. To transform the essentially resistive load of a transmission line so as to present a maximum and constant resistive load to the electron stream of the amplifier.
2. To compensate for the susceptance due to the unavoidable capacitance between the output electrodes.
3. To conduct the rf power efficiently from the electronically active output region to the transmission line load over a distance which may amount to a wavelength or more at ultra-high frequencies.

The output circuit selected for the Coaxitron consists of two over-coupled resonant cavities. This circuit was selected because of lumped-constant filter theory predictions and because the structure is mechanically simple, as shown in Figure 3.

The assumption was made (and later verified) that the performance of a series of coupled transmission line cavities could be made to closely simulate that of "optimum" ladder type filter networks of corresponding complexity. The lumped-constant performance was predicted by calculating the input impedance of ladder networks having various type "B" and "C" responses.

In each case, the initial shunt capacitance was chosen to correspond to that of the Coaxitron output region. The theoretically predicted performance for a two element type "C" network having a 1 db ripple is shown by the solid curves in Figure 10. The resistance component, R, of the network input impedance measures the relative power output response, while the reactive component, X, indicates the incompleteness of compensation of the grid-anode capacitance.

The "double-humped" response represents a considerable improvement over that of a simple resonant circuit, in that the minimum value of R over the band is about equal to the mid-band peak of the simple circuit. Also, there is less reactance over more of the band than for the simple circuit. A slight additional improvement in the R response is predicted for more complicated circuits although the reactance component may actually be greater in some cases.

The design dimensions of the Coaxitron output circuit were determined by a cut-and-try method on an electronic digital computer. This was done for several reasons. First, the rigorous mathematical solution is unwieldy as it involves solution of lengthy transcedental equations. Second, the results of the cut-and-try method agreed closely with measurements made on equivalent cold-test models at approximately 1200 Mc. Third, use of the electronic computer permits more designs to be examined more quickly. Fourth, the

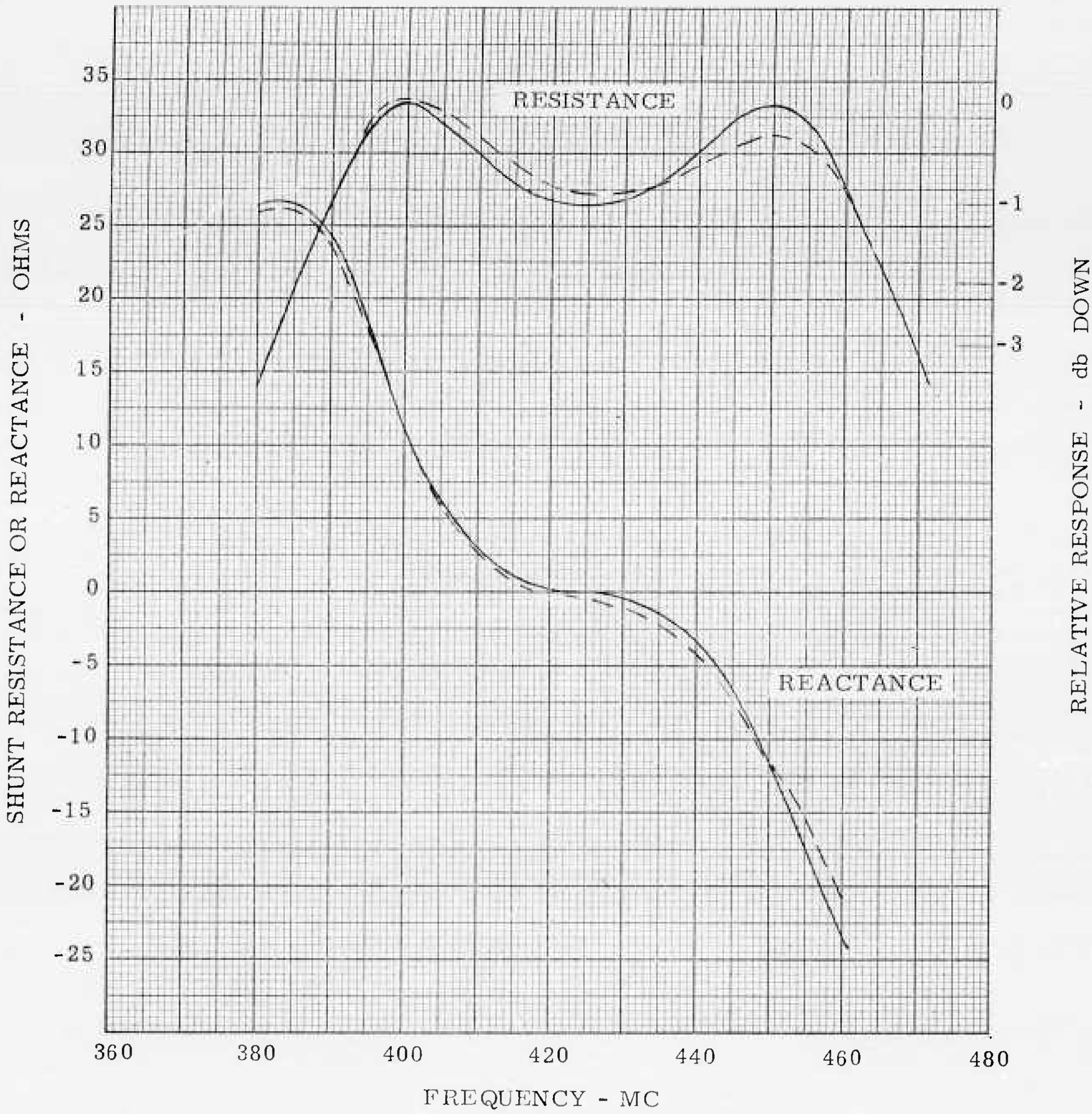

Figure 10 -- Lumped-Constant Performance of a Two Element Type "C" Ladder Network having a 1 db Ripple. The Solid Curves show the Theoretically Predicted Performance, the Dotted Curves the Performance Computed from the Design Dimensions of the Coaxitron.

greatly increased accuracy of the data available from an electronic digital computer permits examination of the effect of small dimensional variations within the circuit.

The cross-section of the generalized circuit assumed for the experimental Coaxitron is shown in Figure 11 and consists of seven sections of coaxial transmission line corresponding to the output geometry of the Coaxitron. Both the re-entrant blocker and the coax-to-waveguide transition were omitted to avoid unimportant added complexity. Line section 1 is the terminated coaxial output line while inductor L_2 represents the coupling spokes. The input impedance is normally calculated at plane F, the mid-point of the active output region where all the electron stream is assumed to be injected.

The electrical equivalent of Figure 11 is shown in Figure 12. Shunting capacitances of discontinuity are shown at the various line junctions.

A typical set of tabulated computer data is shown in Figure 13. For each frequency, the table gives input R, X, and the rms voltage at each line junction for a 5 megawatt output.

The computed performance for the design dimensions of the Coaxitron is shown by the dotted curve in Figure 10, where the relative power output is proportional to the resistance, R. The excellent agreement between the two

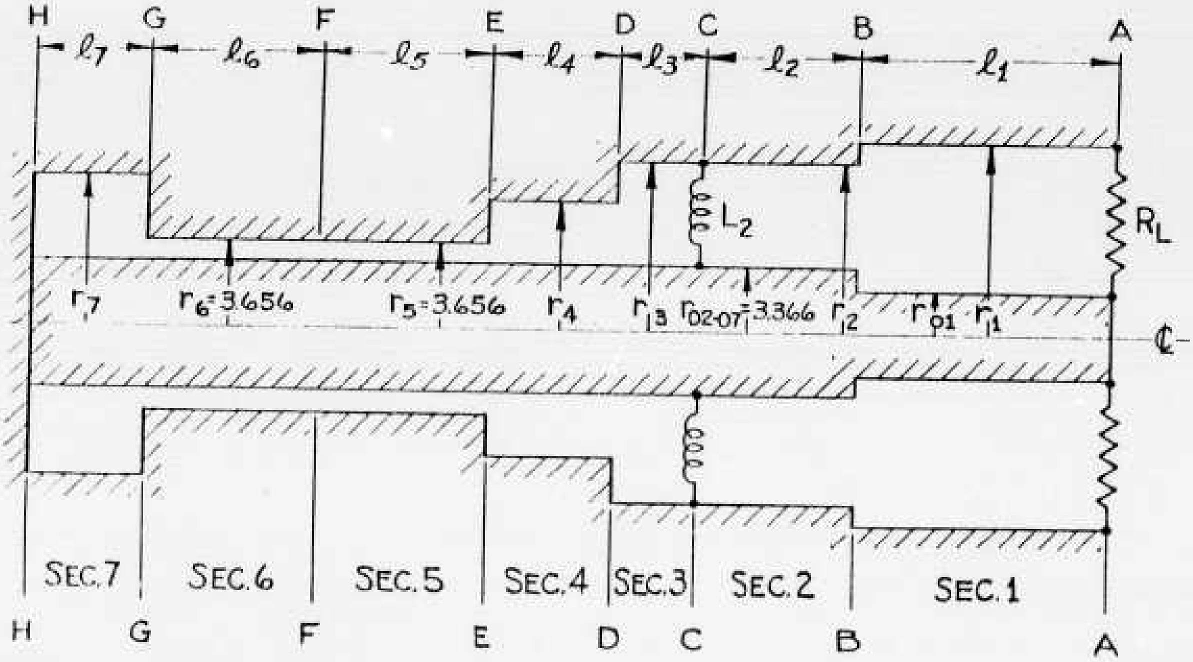

Figure 11 -- Cross-Section of Generalized Coaxial Circuit for Double-Tuned Cavity

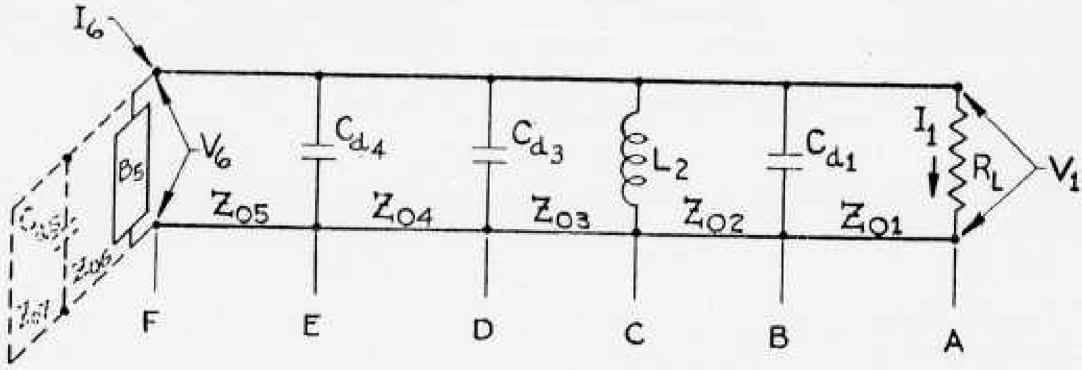

Figure 12 -- Equivalent Circuit for Configuration of Figure 11

CIRCUIT PARAMETERS

R1	R2	R3	R4	R5	R6
63284354 50	43750000 5[illegible]	43750000 5[illegible]	43750000 50	36560000 50	36560000 50

L1	L2	L3	L4	L5	L6
	59500000 5[illegible]	15000000 51		22500000 50	22500000 50

R05	R01	R7	L7
33655000 50	14170648 5[illegible]	41600000 5[illegible]	25613000 50

V1	I1	R LO	INO	Z 01
21213203 54	23670226 52	90000000 51	[illegible] 41	90000000 51

TABULATED DATA

FREQ	R6	X6	V1 V4	V2 V5	V3 V6
35000000 58	18249618 5[illegible]	14[illegible]8814 51	21213203 54 20929527 54	21213203 54 20929527 54	87300631 53 24203984 54
35500000 58	24387540 50	15898639 51	21213203 54 20004261 54	21213203 54 20004261 54	84336256 53 23030912 54
36000000 58	33148113 50	17[illegible]9738 51	21213203 54 19092351 54	21213203 54 19092351 54	81376752 53 21882176 54
36500000 58	45842441 5[illegible]	19344363 51	21213203 54 18196773 54	21213203 54 18196773 54	78426248 53 20762062 54
37000000 58	64425516 50	21884838 51	21213203 54 17321863 54	21213203 54 17321863 54	75489446 53 19675956 54
37500000 58	91664134 50	2345154[illegible] 51	21213203 54 16471284 54	21213203 54 16471284 54	72571592 53 18628419 54
38000000 58	13042994 51	25386788 51	21213203 54 15650364 54	21213203 54 15650364 54	69678692 53 17627353 54
38500000 58	18238868 51	26119542 51	21213203 54 14864977 54	21213203 54 14864977 54	66817533 53 16680085 54
39000000 58	24419114 51	[illegible] 51	21213203 54 14121995 54	21213203 54 14121995 54	63995968 53 15795487 54
39500000 58	299[illegible]8855 51	2113[illegible]695 51	21213203 54 13429290 54	21213203 54 13429290 54	61222951 53 14983558 54
40000000 58	33419844 51	1558[illegible] 51	21213203 54 12795788 54	21213203 54 12795788 54	58508875 53 14255330 54
40500000 58	34467394 51	[illegible]1442571 50	21213203 54 12231135 54	21213203 54 12231135 54	55865764 53 13622527 54
41000000 58	33528459 51	91861546 50	21213203 54 11746406 54	21213203 54 11746406 54	53307487 53 13096361 54
41500000 58	32896342 51	18699287 50	21213203 54 11351576 54	21213203 54 11351576 54	50850085 53 12689619 54
42000000 58	31796206 51	-30244444 49	21213203 54 11056737 54	21213203 54 11056737 54	48512048 53 12409508 54
42500000 58	29964327 51	-18889383 50	21213203 54 10870098 54	21213203 54 10870098 54	46314424 53 12262431 54
43000000 58	29642144 51	-33226160 50	21213203 54 10797160 54	21213203 54 10797160 54	44280972 53 12250022 54
43500000 58	29768748 51	-47768165 50	21213203 54 10840027 54	21213203 54 10840027 54	42437902 53 12369346 54
44000000 58	33115416 51	-71614869 50	21213203 54 [illegible] 54	21213203 54 [illegible] 54	40813429 53 12613167 54
44500000 58	31283419 51	-1250[illegible] 51	21213203 54 11262408 54	21213203 54 11262408 54	39436687 53 12970882 54
45000000 58	29714975 51	-1[illegible] 51	21213203 54 11628499 54	21213203 54 11628499 54	38336213 53 13429745 54
45500000 58	27878599 51	-1[illegible]748 51	21213203 54 12085198 54	21213203 54 12085198 54	37537798 53 13976133 54
46000000 58	2464[illegible] 51	-2164436[illegible] 51	21213203 54 12621284 54	21213203 54 12621284 54	37062087 53 14596170 54
46500000 58	20478451 51	-231[illegible] 51	21213203 54 13227940 54	21213203 54 13227940 54	36922312 53 15278409 54
47000000 58	16188371 51	-2382843[illegible] 51	21213203 54 13892361 54	21213203 54 13892361 54	37122624 53 16010236 54
47500000 58	12397861 51	-23[illegible] 51	21213203 54 14607568 54	21213203 54 14607568 54	37657577 53 16782010 54
48000000 58	93988319 50	-22163976 51	21213203 54 15363514 54	21213203 54 15363514 54	38512834 53 17585021 54
48500000 58	[illegible] 50	-20780177 51	21213203 54 161[illegible] 54	21213203 54 161[illegible] 54	39666953 53 18411632 54
49000000 58	53506786 50	-19187828 51	21213203 54 169[illegible] 54	21213203 54 169[illegible] 54	41093698 53 19250086 54
49500000 58	41119584 50	-17749868 51	21213203 54 1781[illegible] 54	21213203 54 1781[illegible] 54	42764458 53 20112398 54
50000000 58	31844621 50	-16644281 51	21213203 54 [illegible] 54	21213203 54 [illegible] 54	44640[illegible]35 53 20576177 54

SUMMARY

R6 MN	R6 MX	RATI	V1 MX V4 MX	V2 MX V5 MX	V3 MX V6 MX
18238868 51	34467394 51	188[illegible] 5[illegible]	21213203 54 14864977 54	21213203 54 14864977 54	66817533 53 16680085 54

THIS DESIGN SATISFIES THE
MINIMUM REQUIREMENTS

Figure 13 -- Photographic Reduction of a Typical Set of Tabulated Computer Data

sets of curves shows that the "optimum" lumped-constant performance has been achieved in the distributed-constant theory and that lumped-constant filter theory gives reliable guidance in designing complicated long-line circuitry.

The final dimensions were determined by adjustment during cold-testing of the actual Coaxitron parts. This was done to allow corrections to be made for mistuning effects due to minor configuration details in the active region, to correct for inexact design information as to the effective spoke coupling inductance, to compensate for the influence of the residual VSWR in the coax-to-waveguide transition, and to allow for the influence of the re-entrant blocker.

Some parts used during the cold-test were full-sized but were especially made to permit rapid adjustment and to allow the inclusion of measuring probes. The band-pass response was determined by the power delivered to a matched waveguide load with respect to the power fed into a voltage probe located at the mid-plane of the active output circuitry (corresponding to plane F-F in Figure 11). The cold-test response shown in Figure 8 was set to have the same one decibel ripple as Figure 10, but with somewhat wider bandwidth, i.e., the three decibel bandwidth is 88 megacycles instead of 80 megacycles. The cold-test adjustment process was facilitated by the use of the computed curves shown in Figures 14 through 17, which predict the general effect of various independent adjustments on the output response.

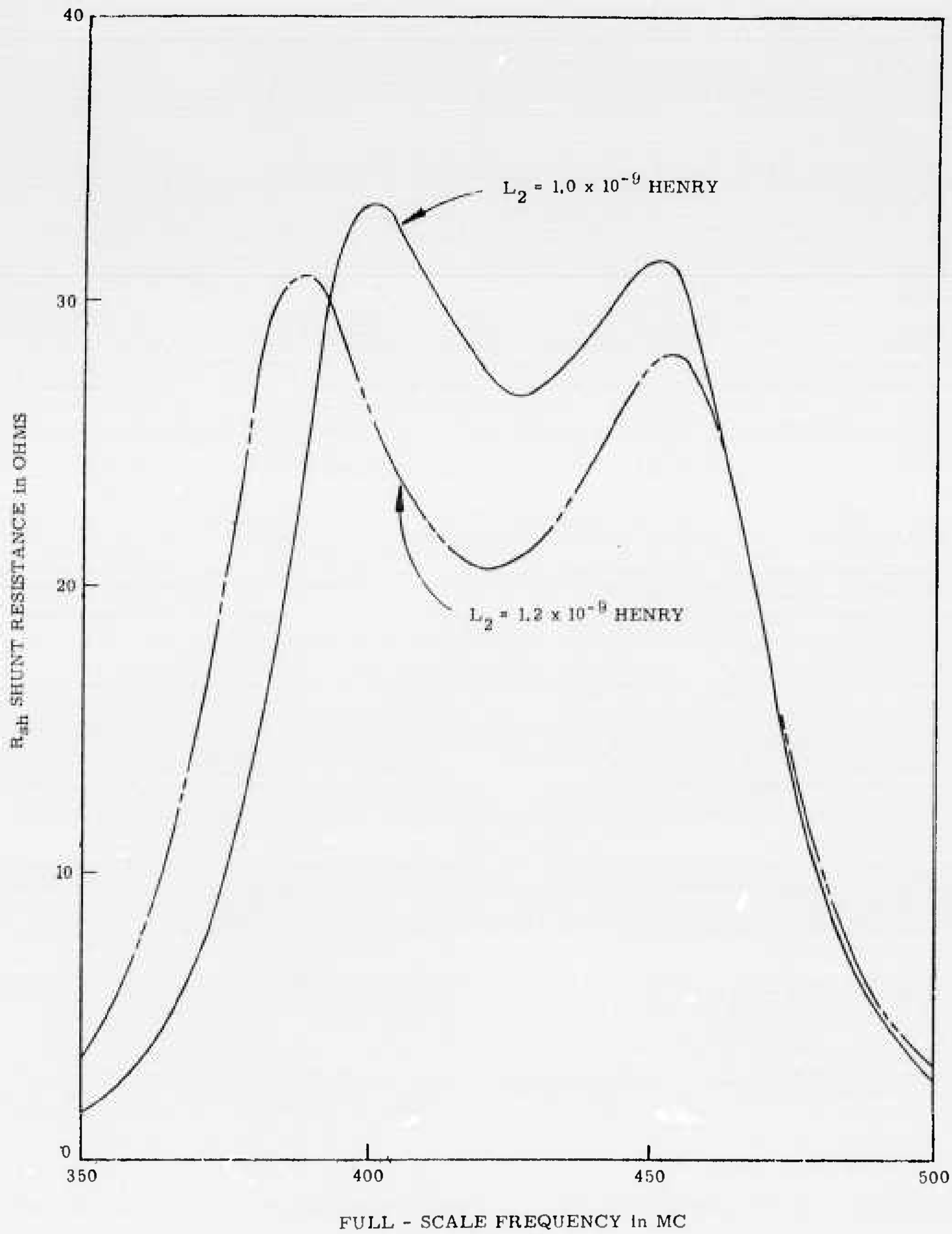

Figure 14 -- Calculated Effect of Increasing the Coupling Inductance of Optimum Double-Tuned Cavity Design

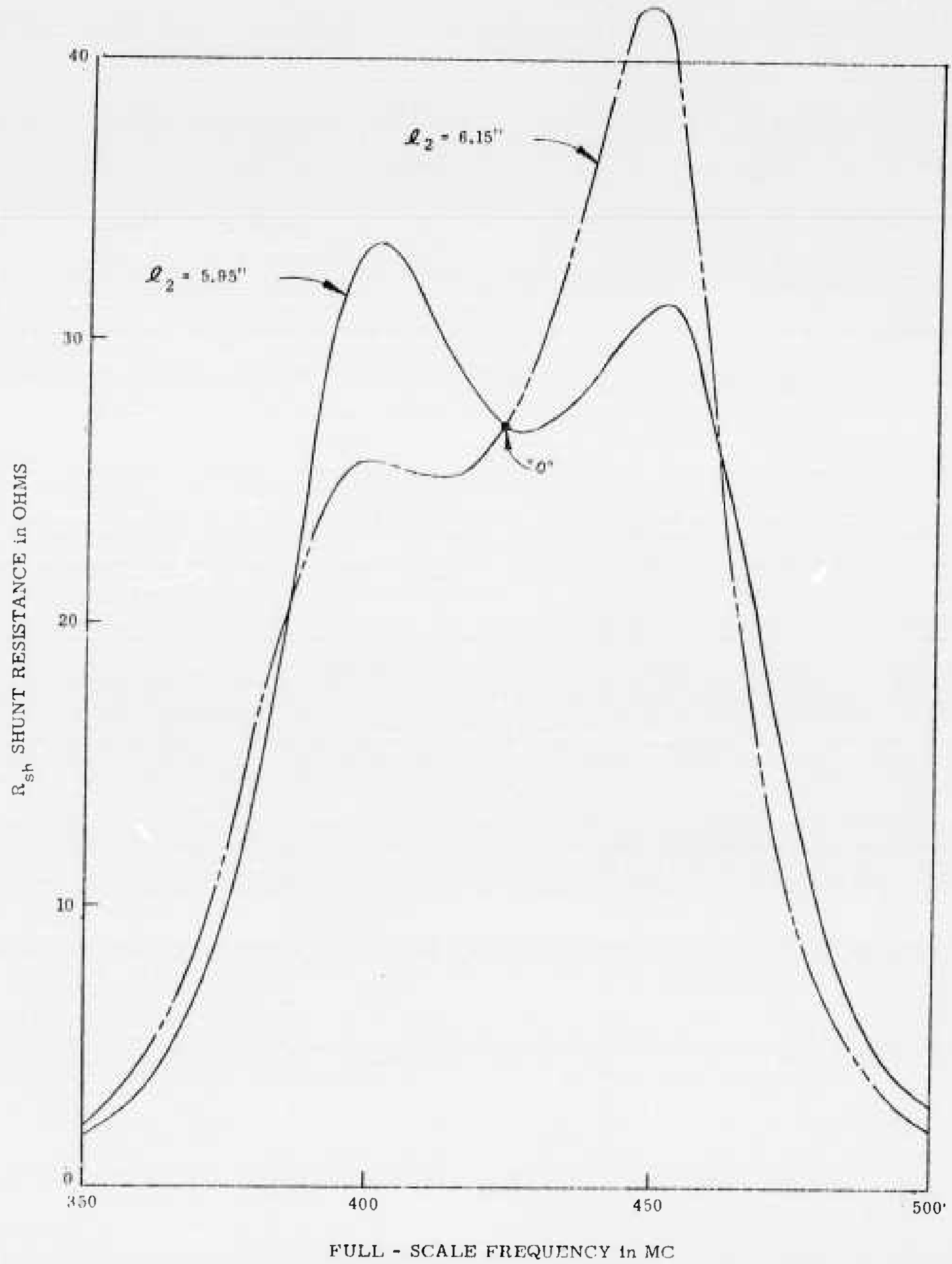

Figure 15 -- Calculated Effect of Increasing Line-Length ℓ_2 between Coupling Inductors and Output Section of Optimum Double-Tuned Cavity.

It has been observed that for small changes in ℓ_2 the point marked "o" is invariant.

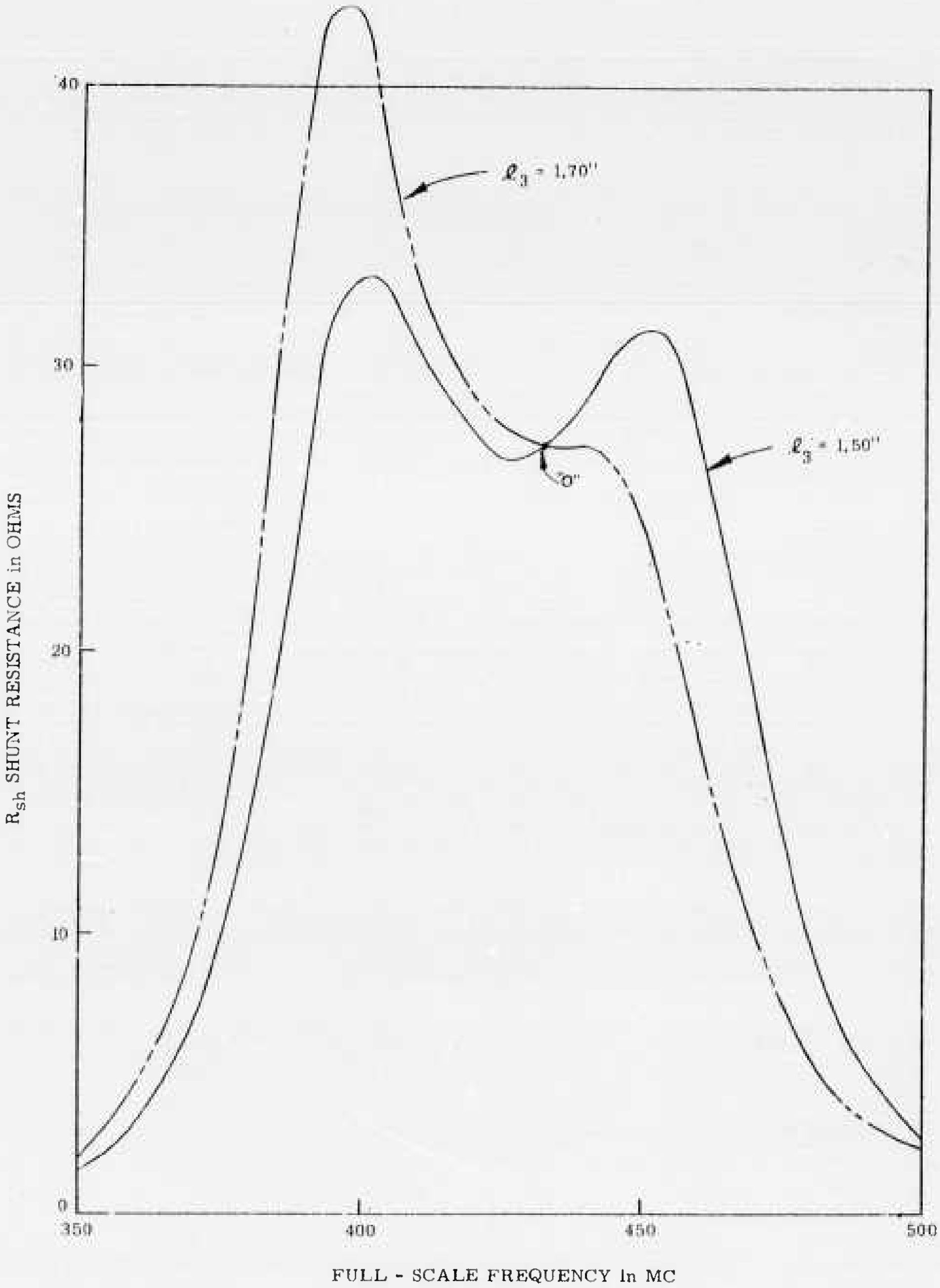

Figure 16 -- Calculated Effect of Increasing Line-Length between Coupling Inductors and Active Length of Optimum Double-Tuned Cavity.

It has been noticed that for small changes in ℓ_3 the point marked "o" is invariant.

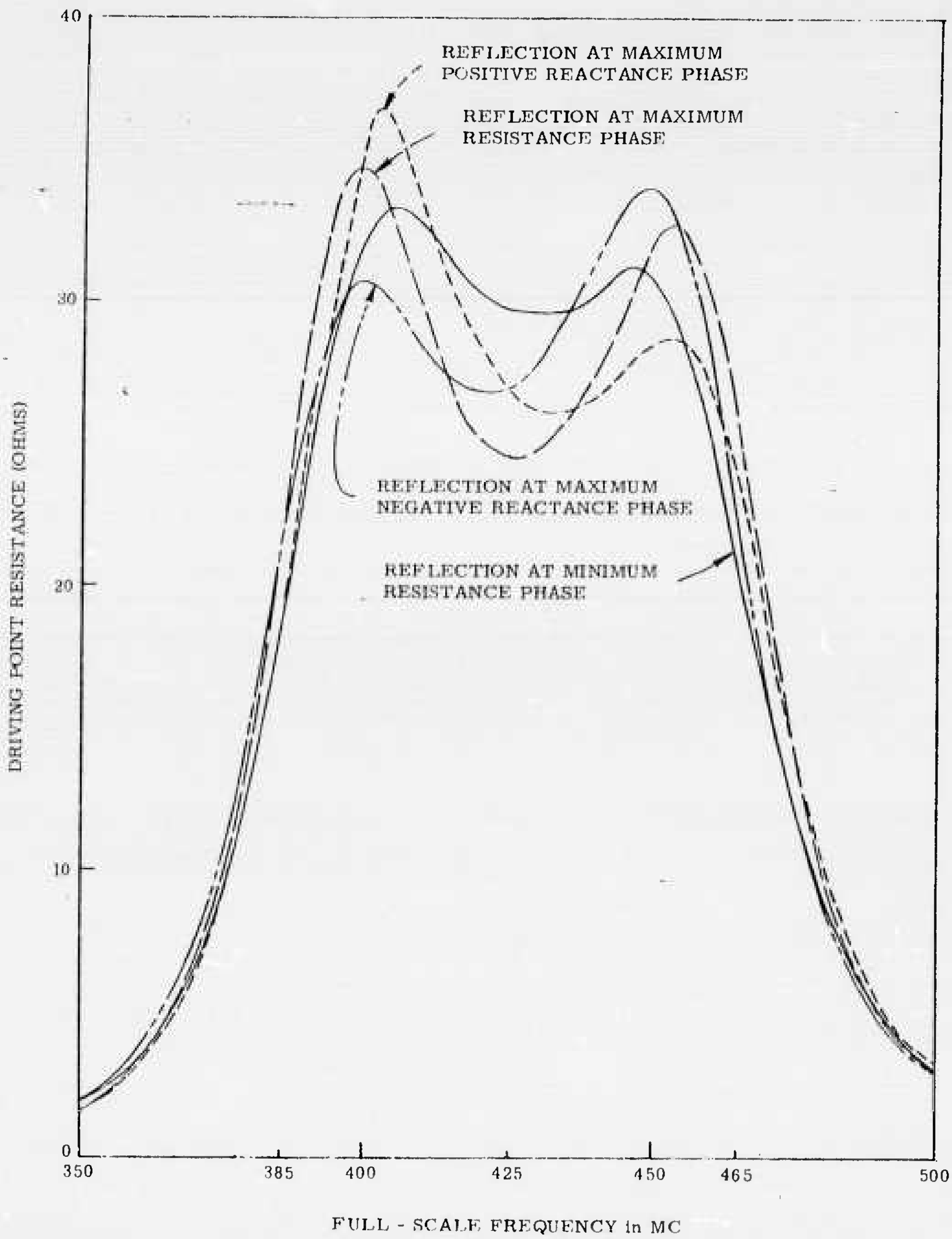

Figure 17 -- Theoretical Maximum Effect due to 1.1:1 VSWR in Output Line on Optimum Double-Tuned Cavity Response (for all phases of reflection)

The finally selected length of the auxiliary output cavity and the positions of the spokes, the position of the coaxial line end cap, and wave-guide plunger were all within a fraction of an inch of the anticipated values.

During this cold-test the voltage distribution was also explored. Several results indicated that operation in the desired mode was assured. First, a voltage maximum occured near the mid-plane of the active region, as measured by a series of test probes in a dummy grid cylinder. Second, a voltage maximum was found at the mid-plane probes (see Figure 5) at the outer periphery of the re-entrant blocker. Third, relatively low voltages were observed on the blocker probes nearest the slave-end and load-end cavities.

Freedom from parasitic modes in the pass-band was indicated by a lack of observed sharp peaks or dips in the response. Also, the relatively constant probe voltage distribution around the outer circumference of the re-entrant blocker indicates the absence of circumferential modes.

The load resistance versus frequency response (Figure 7) measured at moderate power levels indicates resistance values somewhat lower than the theoretical predictions of Figure 10. Several factors may have contributed to this difference. First, the bandwidth was widened during cold-test adjustment. Second, the grid-anode capacitance was increased slightly

by the addition of the second grid. Third, the energy stored in the re-entrant blocker decreases the R x BW product slightly. Fourth, the electron current was injected along the entire active length of the output region instead of at the mid-plane as assumed earlier. The effectiveness of the injected current is reduced by a few percent because each contribution along the active length undergoes a different phase and amplitude change by the time it combines with others to form a single current into a common load. Fifth, power losses in the output circuitry were neglected. Sixth, the dc to rms conversion factor may vary slightly from the 1.1 as assumed in calculating the R from formula 2. Seventh, there may have been some inaccuracies in measurements and, eighth, the rf voltage distribution along the cathode-grid region may not be uniform since the input slave-end tuning was not optimized.

Coaxitron Input-Circuit Design

The input circuitry of a Coaxitron amplifier should also be wide-band to achieve completely fixed-tune operation. A design has been developed which should be satisfactory electrically and is feasible to construct. The design philosophy is quite different from that used above for the Coaxitron output circuit and will be outlined prior to describing the design itself.

The functions of the input circuit of a Coaxitron amplifier are:

1. To inject into the grid-anode region electron current pulses of a magnitude sufficient for the desired power output.

2. To achieve a reasonable degree of uniformity of current injection along the active length.

3. To provide a constant and essentially resistive termination for the rf transmission line from the driver.

The current injected through the grids is a large fraction of that drawn from the emitting matrix facing on the cathode for typical Coaxitron operating voltages.

The emission current drawn, in turn, follows closely the parallel-plane diode formula:

$$i = \frac{2.334 \times 10^{-6} V_{gk}^{3/2}}{d_{gk}^2} \qquad (3)$$

Based on this expression, the grid-cathode voltage required for a given Coaxitron plate current is shown by the lower curve of Figure 18. A dc plate current of say 500 amps would require a peak voltage swing of only 300 volts. This low voltage accounts for the relatively good power gain of the Coaxitron. On the other hand, a very low input impedance may be expected, as will be discussed later.

Uniformity of current injection requires uniformity of rf voltage along the cathode. This may be approximately achieved by appropriate adjustment of a slave-end input cavity in a manner similar to the output-circuit case. Calculations made on a digital computer indicate that a fixed-tuned slave-end

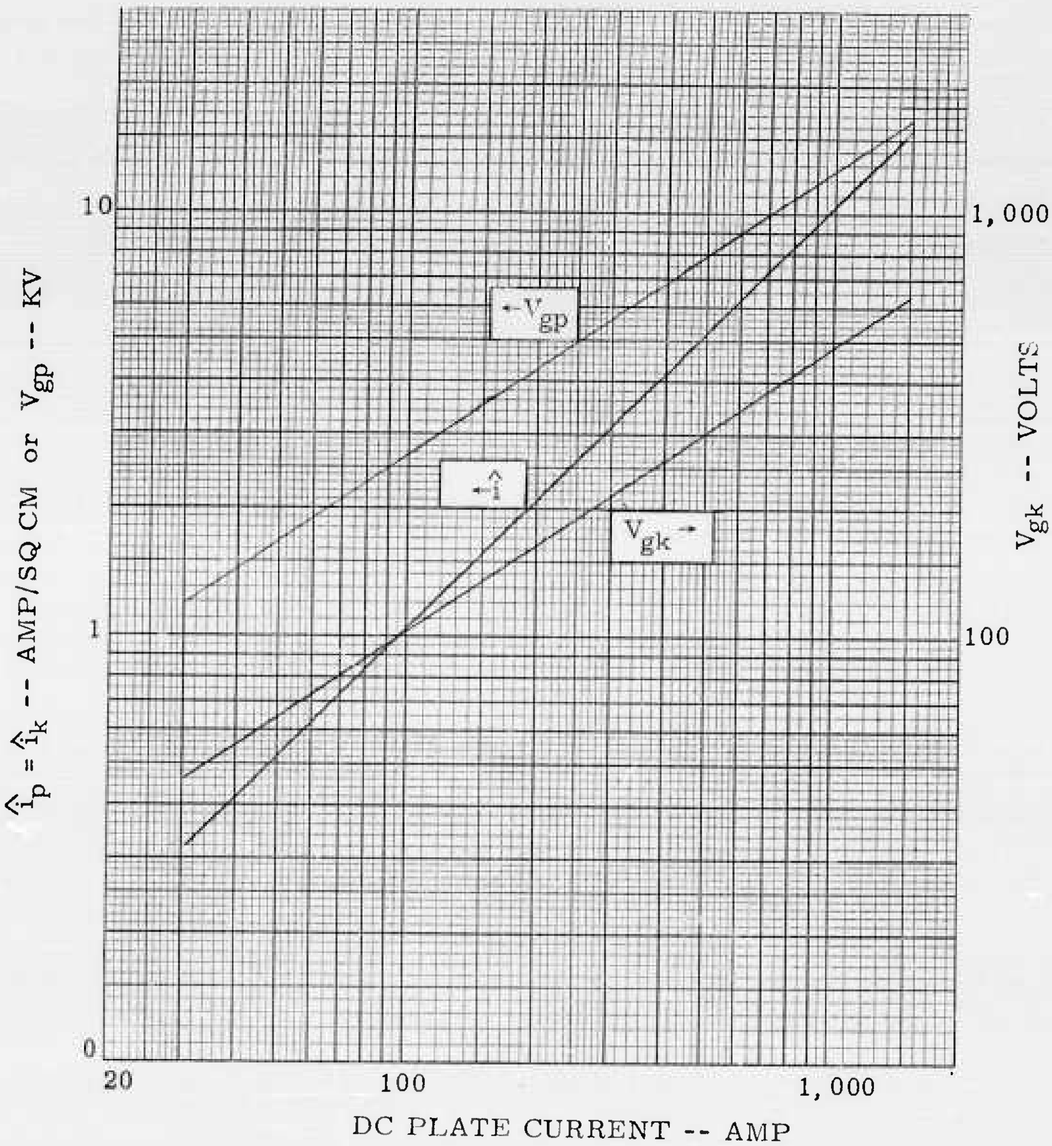

Figure 18 -- Coaxitron Voltage Requirements where the grid-cathode spacing is .019" and the grid-plate spacing is 0.285".

$$\hat{i}_p = \frac{2.334 \times 10^{-6} \left(V_{gk}^{1/2} - V_{gp}^{1/2}\right)^3}{d_{gp}^2}$$

$$\hat{i}_k = \frac{2.334 \times 10^{-6} V_{gk}^{3/2}}{d_{gk}^2}$$

$$I_B = \frac{\hat{i}_p \times \text{Area}}{\pi}$$

reactive termination is satisfactory for the 385-465 Mc operating range. The calculations consider the grid-cathode active region as an extremely "lossy" transmission line due to the electron emission current being drawn. They also account for the effect on the relative power output of the phase and amplitude variations of the electron current along the active length. The calculated impedance looking into the driven end of such a grid-cathode region is only about 0.22 ohm and varies slowly with frequency and drive level. Typical curves of input impedance and phase angle are shown in Figure 19.

The requirement of terminating a typical 50 ohm driver transmission line thus becomes essentially a problem of designing a wide-band transformer having a 250 to 1 impedance ratio. A tentative design has been worked out for such a transformer. It too is fixed-tuned and transforms the complex impedances represented in Figure 19 to a reasonably good match for a 50 ohm line as indicated in Figure 20. An even better match is believed to be obtainable with further design effort.

Basically, the transformer consists of two tandem sections of quarter-wave coaxial line with a shunt correcting stub, somewhat along the lines suggested by E. M. Broad*. A simplified longitudinal cross-section is shown in Figure 21. The relatively low surge impedances of the 0.828 ohm section and the 0.322 ohm stub are obtained by interleaving radial fins extending from the coaxial walls. The impedance of such lines was determined by using

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* High-Power Radio-Frequency Broad-Band Transformers - Post Office Electronics Engineers - Jv 51, Pt 1, Ap 58, pages 8-13

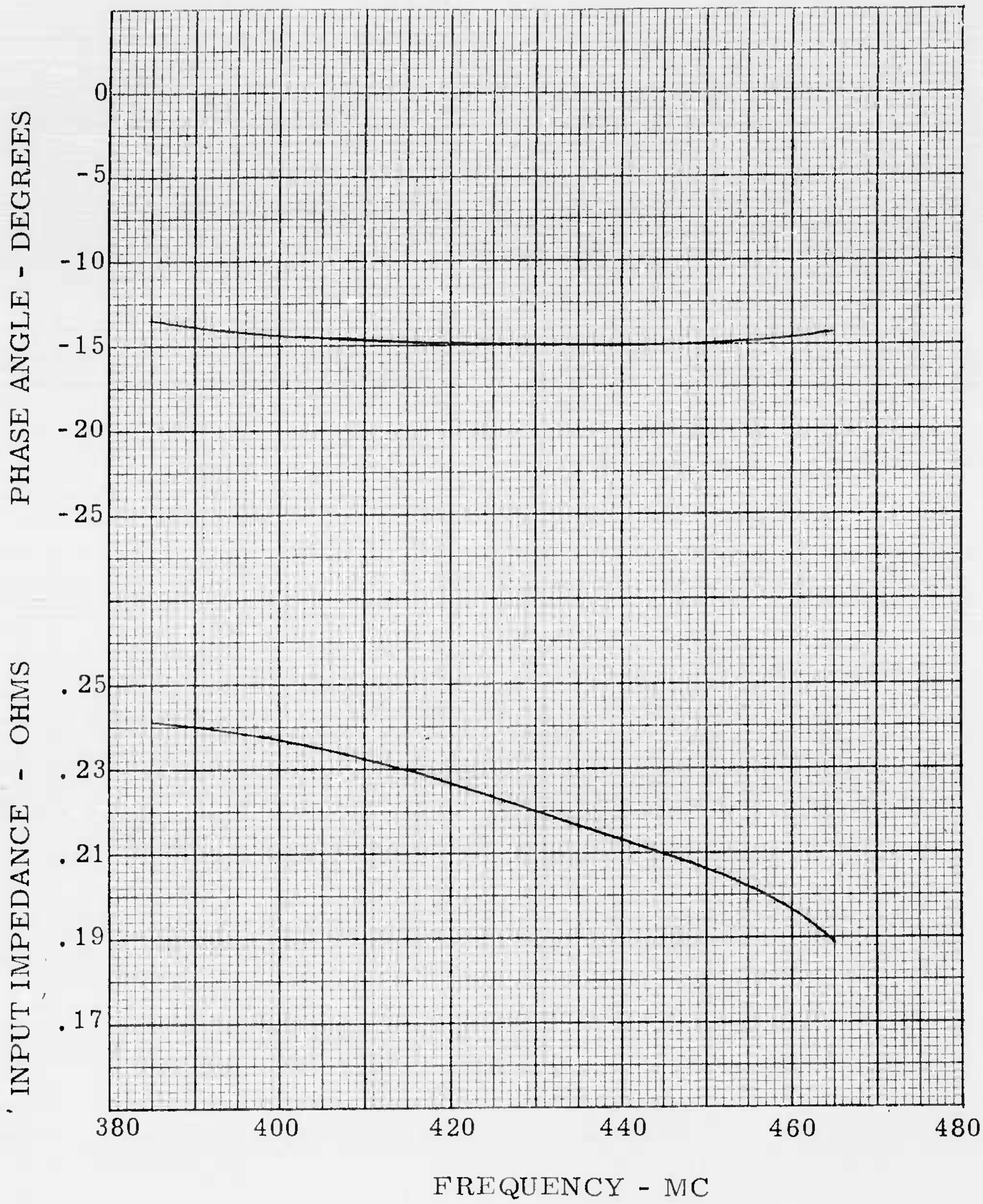

Figure 19 -- Input Characteristics of the Active Portion of the Grid-Cathode Structure of the Coaxitron.

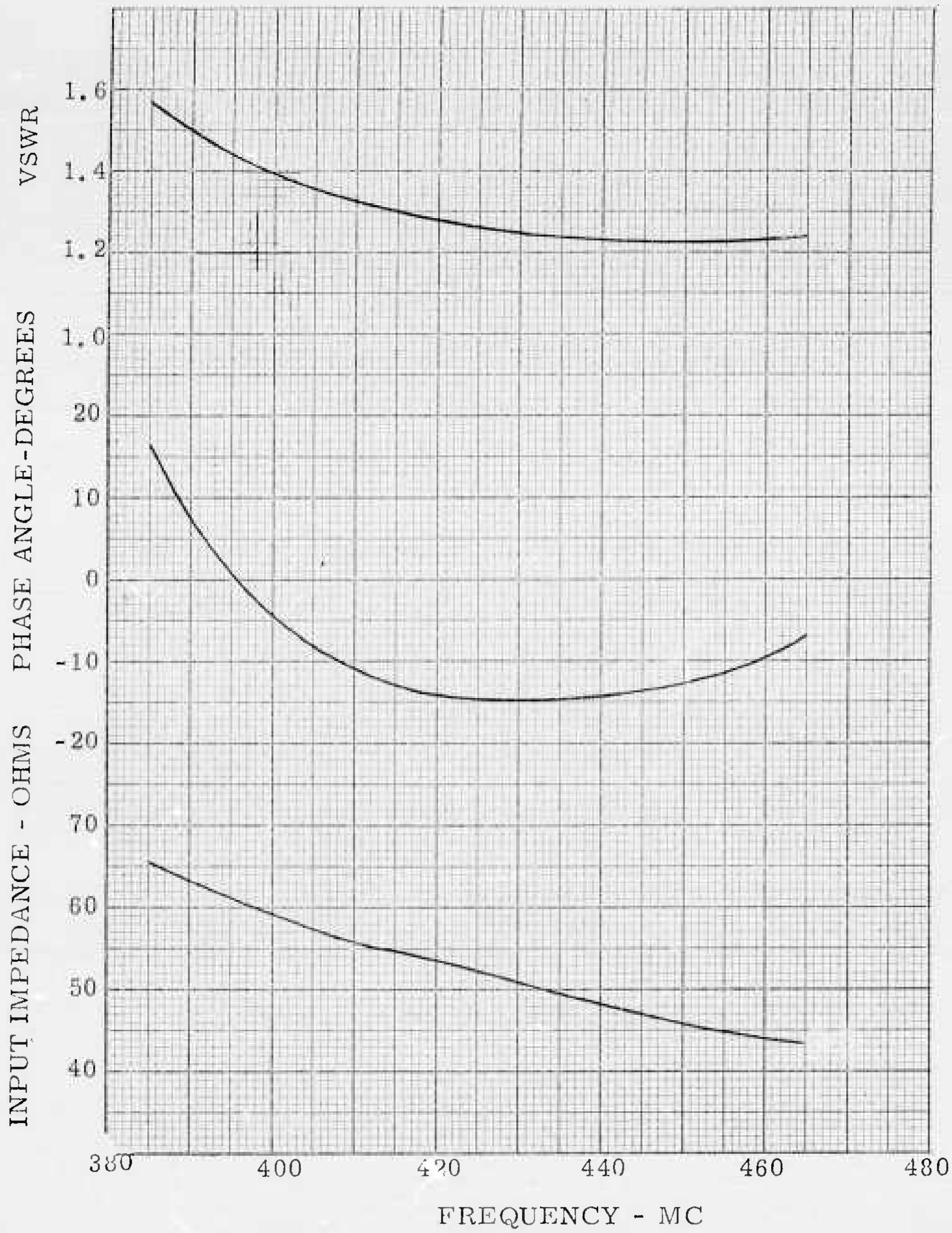

Figure 20 -- Input Impedance vs Frequency for a Compensated Two-Seetion Matching Transformer Conneeted to a Coaxitron Active Grid-Cathode Cireuit. The VSWR shown is that Predicted for a 50 OHM RF Driver Transmission Line.

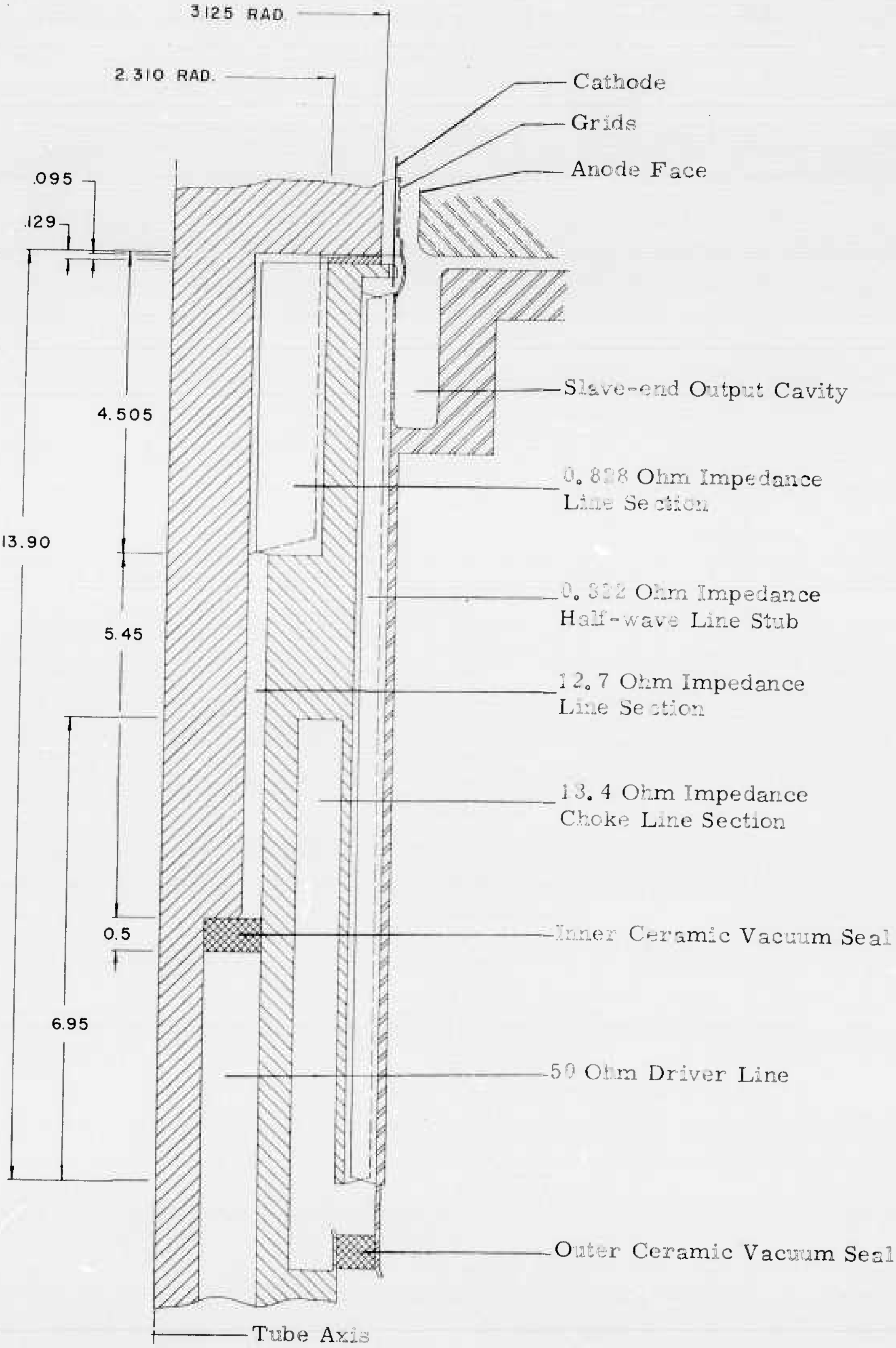

Figure 21 -- A Simplified Longitudinal Cross-Section of the Coaxitron Broadband Input Circuit. Dimensions are in Inches.

resistance-paper analogues. The portion of the 0.828 ohm line section adjacent the cathodes consists of a ceramic radial transmission line. Likewise, the lower end of the 12.7 ohm section consists of a short ceramic coaxial line, which, incidentally, is on the axis of the whole tube.

Filament heating power may be applied across the outer ceramic ring, thus permitting the upper ends of the cathodes to be grounded as a part of the input slave-end circuit. This will allow a considerable simplification in the construction of the grid block over that shown in Figure 5. Leakage of rf power at the filament heating terminals should be prevented by the 13.4 ohm quarter-wave coaxial choke cavity.

The input transformer just described was selected after checking numerous designs on the digital computer. Three section transformers offered no significant improvement in performance and were more complicated to fabricate.

Design Objective D - "Pulse width: 25 microseconds minimum".

This pulse width should be attainable without difficulty. Although the provisional testing to date has been at a pulse width of 10 microseconds, RCA experience with the matrix-cathode life tests of the RCA tube type 6952 indicates that the current requirements stated previously represent a conservative emission demand for matrix-cathodes. Likewise, RCA experience with

the high anode dissipation requirements for the long pulse service of the Developmental Tube Type A-2346 indicate a sound anode design.

Design Objective E - "Duty Factor 0.01 minimum".

This should be obtained without difficulty. The matrix-cathode is quite capable of this service while the anode and grid heat dissipation abilities are very adequate for the average power. Also, the provisional testing performed to date has been satisfactory at a duty factor of 0.003, as dictated by the modulator equipment available.

Design Objective F - "Efficiency 30 percent minimum, when operated under power output conditions specified in C, above".

Dynamic operation at low voltages has demonstrated efficiencies up to 45%. Further improvement may be expected at high operating voltages. Most of the data taken for the curve shown in Figure 7 was in the 10-12 kv E_B range, while the anticipated plate voltage required for full power output is approximately 22 kv.

For maximum efficiency, the dc plate voltage, E_B, must just exceed the ac plate voltage, V_p, by a voltage V_{gp} to permit the electron current to cross the output region without space charge limiting. The V_{gp} required in terms of the Coaxitron dc plate current, is shown by the top curve of Figure 18. Too high an E_B causes needless plate dissipation while too low an E_B results in reduced power output due to plate current wave distortion. This was generally

verified during the provisional testing. Below are two sets of data showing the improvement in efficiency at higher E_B.

Typical Low Power Test	Anticipated High Power Performance
P_o = 600 kilowatts	5000 kilowatts
R = 22 ohms	22 ohms
I_B = 150 amperes	433 amperes
V_p = 5.1 kilovolts	14.8 kilovolts
V_{pg} = 3.5 kilovolts	7.1 kilovolts minimum
E_B = 8.6 kilovolts	21.1 kilovolts minimum
Eff. = 46.5%	52.5%

On the other hand, a drop in efficiency is to be expected near the edges of the frequency band due to the increased reactive component of the load impedance because the plate voltage swing V_p is higher than would be required for a given plate current to develop the same power in a load consisting of only the resistive component. For example, if the reactance and resistance are each equal to 22 ohms, the total impedance would be 1.41 x 22 or 31.1 ohms. Consequently, for the given plate current of 433 amp. the plate voltage V_p will be 1.41 times that of the previous example, or 21.0 kv. The new dc plate voltage thus becomes 28.1 kv and the efficiency 5000 ÷ (433 x 28,100) = 41.1%.

Design Objective G - "Power Gain: A maximum consistent with the electrical design of the tube".

The power gain of the Coaxitron as determined by the present test data is very good. The typical gain at a 1 Mw power output level is about 30:1 where the

estimated drive power is approximately 35 kw. The high gain is the result of two factors. First, a relatively low grid-cathode voltage swing is needed to drive the required current due to the zero bias operation permitted by the high mu. Second, no special swamping is needed for broad-banding the input circuit. A curve showing the relationship of the quiescent I_B versus E_b dc is shown in Figure 22.

Design Objective H - "Cathode: The cathode shall be a matrix-oxide type". The Coaxitron amplifier uses matrix-oxide cathodes of the type which have given outstanding performance in other applications. These cathodes require relatively low heating power and easily provide an emission of 10 amperes per square centimeter. The emission density required for a Coaxitron dc plate current of 450 amp is considerably less than this. Neglecting grid absorption, a cathode current density of only 4.7 amp per square centimeter would be required according to the middle curve of Figure 17. Special Developmental A-2346 tubes using these cathodes have demonstrated a power output of over 5 Mw at a pulse length of 2000 microseconds. Furthermore, the RCA 6952 exhibits long life with a power output of over 2 megawatts at a pulse length of 13 microseconds and a peak cathode loading of 15 amperes per square centimeter.

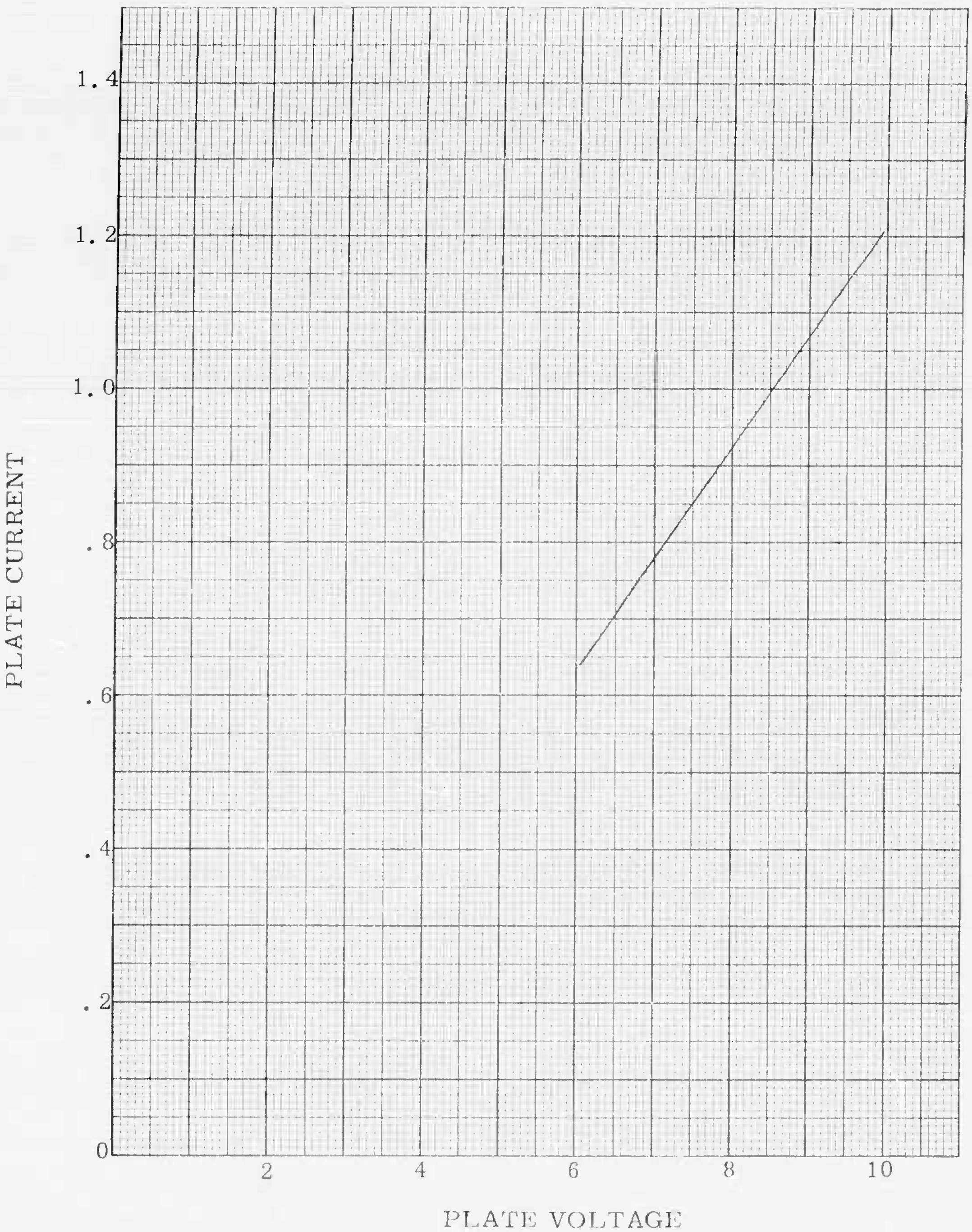

Figure 22 -- Plate Current vs Plate Voltage for the Model B Coaxitron. These Values Correspond to the Quiescent for Class B Operation.

Design Objective I - "Cooling: In order to provide adequate cooling of the tube, suitable coolant courses through the tube elements with accessible connectors shall be provided".

To meet this objective, passages have been provided to cool the anode block, the grid block, both ends of the output cavity, the coupling spokes, the cathode mounting fixtures, and the anode support insulators; and, if necessary at high-power outputs, the output coaxial transmission line inner conductor can easily be cooled. That adequate cooling has been provided for the power levels achieved is evident because no excessive temperatures were noted during the operation. These coolant courses can be seen on the sectional drawings shown in Figure 4 and Figure 5.

The coolant used during the provisional testing of the Coaxitron was Minnesota Mining and Manufacturing Company's FC-75. This fluid was selected because its high inherent resistance reduced leakage currents and because FC-75 facilitated effective bypassing of the dc plate lead.

Design Objective J - "Load Voltage Standing Wave Ratio (VSWR): The tube shall be designed for operation into a load having a VSWR of 1.5:1 for all phases, without evidence of operational instability".

Since the device is inherently a linear amplifier rather than an oscillator, no operational instability would be expected. To verify this, the experimental Coaxitron was operated into a waveguide having a VSWR of 2.4:1. This was obtained by disconnecting the normal load and allowing the rf energy to radiate into free space from the open end of the wave guide. The Coaxitron

was tested under these conditions at frequencies near the band-edge where the tube load becomes quite reactive. No signs of instability or spurious modes were observed.

Two other factors also enhance the stability of the Coaxitron amplifier. The extra isolation of the input and output circuits provided by the double-grid is the first and the fact that the load is symmetrically coupled to the output circuit is the second.

SECTION VII

ACCESSORY EQUIPMENT ACQUIRED UNDER THE CONTRACT

Processing Equipment

In order to assure adequate processing of the experimental Coaxitron, several modifications were made to the vacuum system and other special equipment was acquired. A special base plate for off-center exhausting of the experimental Coaxitron and a new liquid-nitrogen trap were designed to facilitate proper vacuum processing. In addition, an 8000 ampere continuously variable filament supply, a dc bias and grid bombarding supply, and a plate bombarding supply were acquired.

Test Equipment

A special tunable input circuit was designed and built for the experimental Coaxitron. The necessary coaxial drive line and associated fittings were acquired for the input circuit rf drive connections. A wave-guide, water load, wave-guide slotted line, wave-guide flexible section, and a wave-guide transition and plunger were acquired for the output circuitry as well as a special full size wave-guide load for cold probe purposes. The 3/4 height 2300 wave-guide output line and fitting can be seen in the photograph of Figure 23.

Model Study Apparatus

A special 1 Mc analogue was designed and built to study the voltage and phase relationship along the active portion of the tube and re-entrant blocker. A

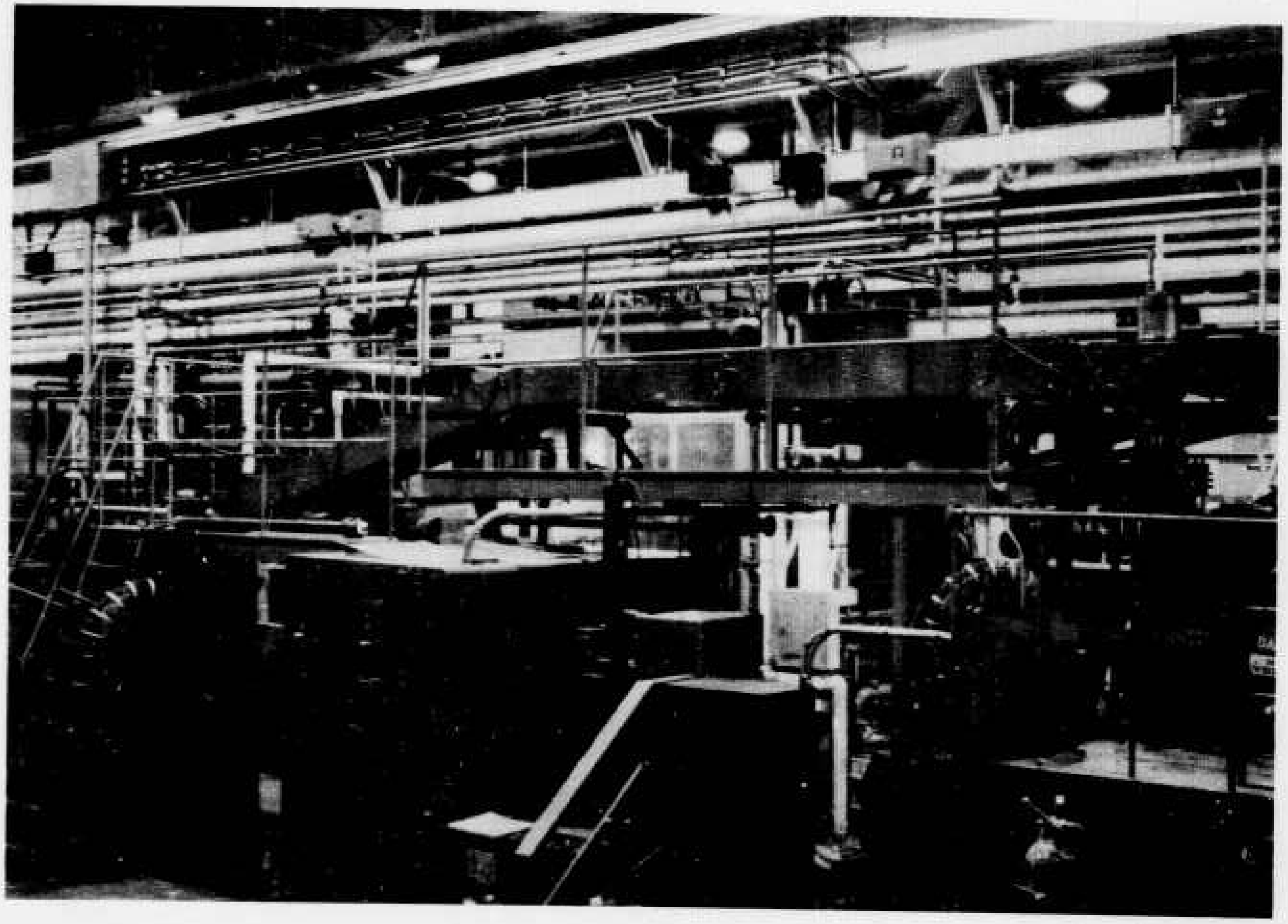

Figure 23 -- Test Set-up of the Model B Coaxitron Showing the 2300 Waveguide and Water Load. The Coaxitron is at the Extreme Right, the Water Load at the Left. The Center Portion of the Waveguide is the Slotted Line. The Equipment Under the Waveguide Platform is the Rf Driver.

photograph of this analogue is shown in Figure 24.

Much of the preliminary design work was done using a 1/3 scale model at a frequency of 1200 Mc. The photograph of Figure 25 shows the 1200 Mc Coaxial Cavity, the 1200 Mc Coaxial Taper Transition and the 1200 Mc Coaxial Special Low Impedance Slotted Line used for these tests.

2000 Mc Adjustable Wave-Guide to Coaxial Transition

The preliminary design work of the coaxial-to-wave-guide transition was done at 2000 Mc. Figure 26 shows a photograph of the special adjustable wave-guide to coaxial line transition necessary for this work. Figure 27 shows a photograph of various coaxial tapered transitions and of several special coaxial impedance terminations.

Coaxitron Model A

Figure 28 shows a photograph of the first experimental Coaxitron built. This Model A Coaxitron, however, was unlike the Model B Coaxitron in that it had single-tuned output circuit inductively coupled into an 8 ohm load which had to be transformed by a broad-band step transformer to the 100 ohm load. In addition, as shown on the curves of Figure 30, the coaxial-to-wave-guide transition required pre-setting of the wave-guide shorting stub at each individual frequency. The first experimental Coaxitron employed thoriated tungsten cathodes to permit repeated rebuilding to test various modifications of the new features such as the re-entrant dc blocker as described previously.

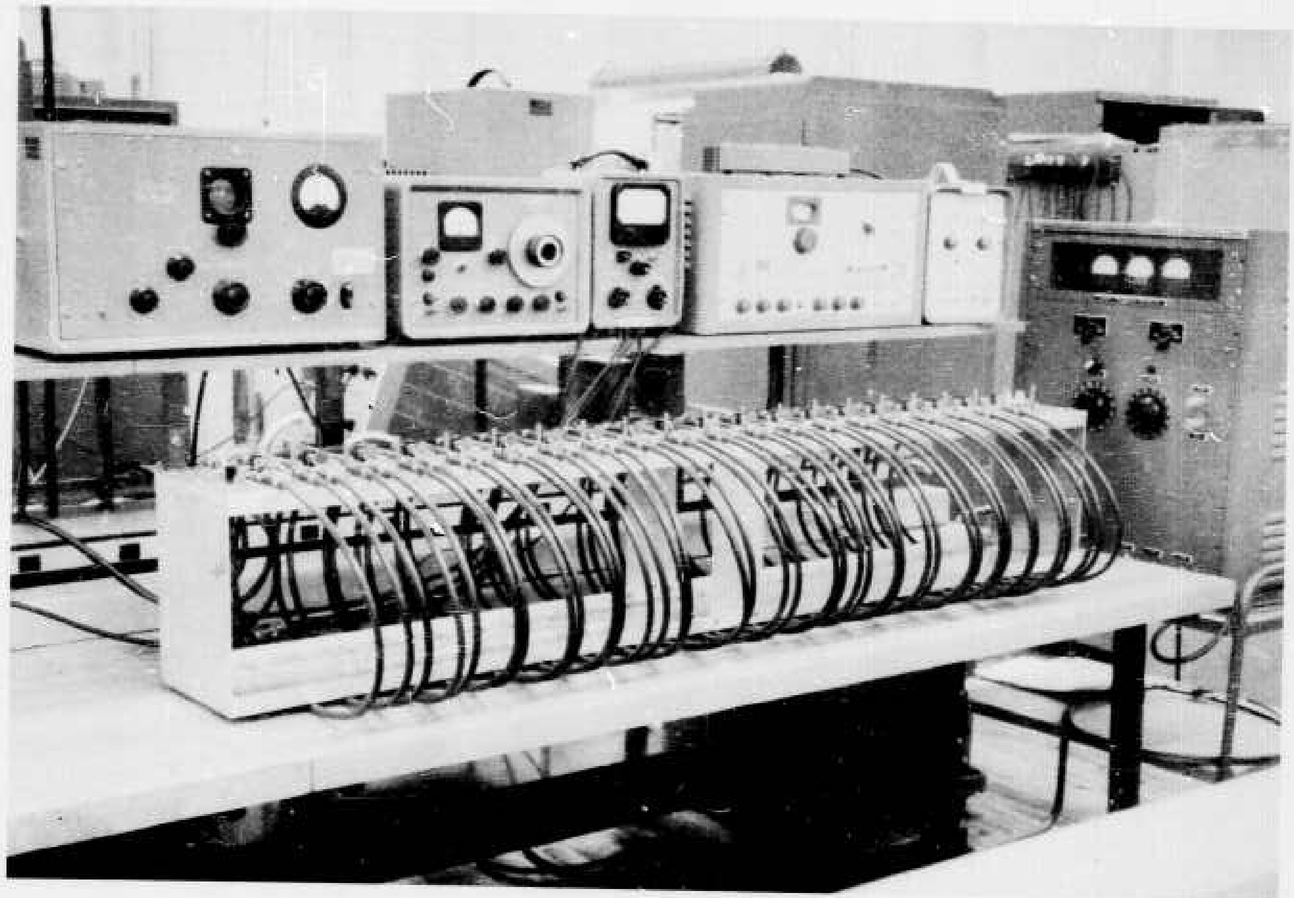

Figure 24 -- A Photograph of the Special 1 Mc Analog Designed to Study the Voltage and Phase Relationship of the Model B Coaxitron Along its Active Portion and Re-entrant Blocker.

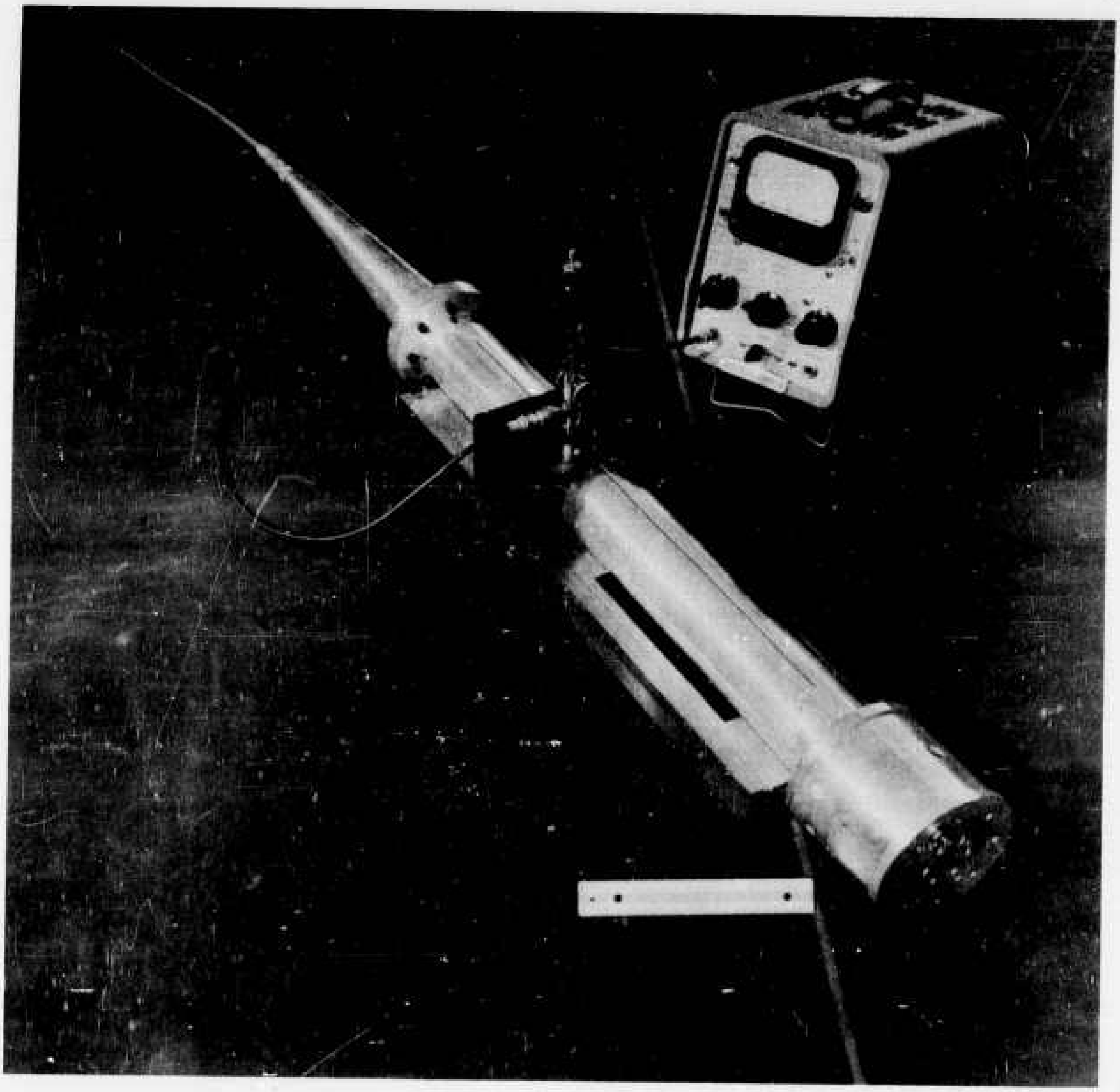

Figure 25 -- Scale Model Single-Tuned Cavity One-Third Size, Coaxial Slotted Line and Coaxial Transformer Shown Assembled (Scale is 6-1/2" long)

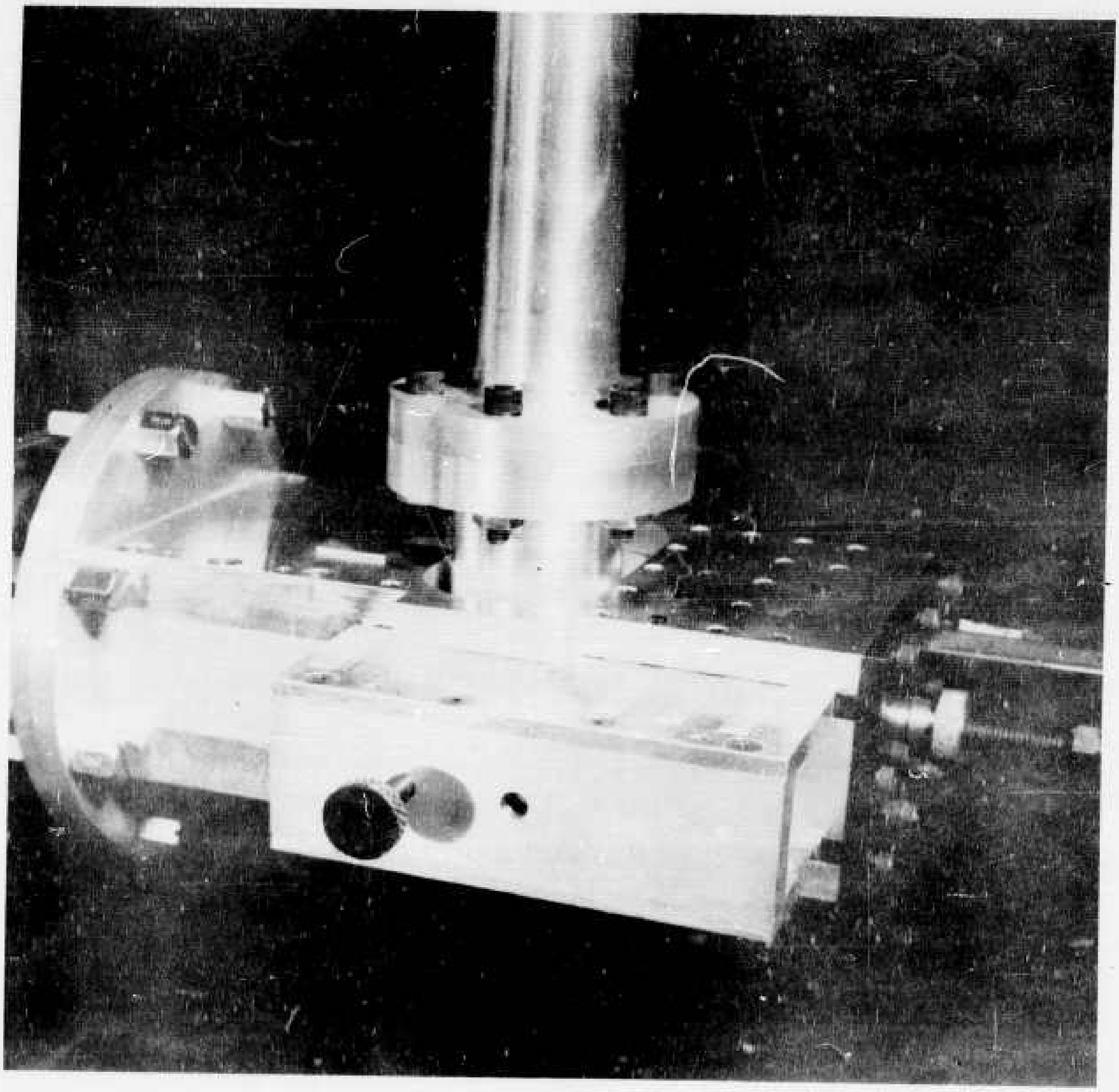

Figure 26 -- Side View of Scale Model Adjustable Waveguide-to-Coaxial Transition in 3.095" x 1.161" Waveguide, Showing Slide-Box Which Permits Adjustment of the Transverse Position of Coaxial Line in the Waveguide.

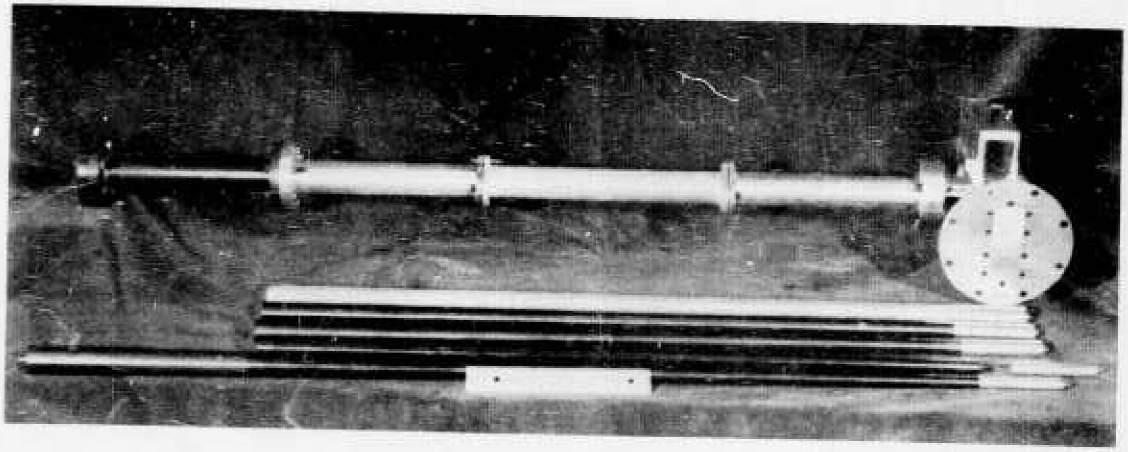

Figure 27 -- Adjustable Transition Shown Connected to Outer Conductor of the Slotted Line. In the Foreground are Various Size Lossy Tapered Inner Conductors, all of Which Taper from Some Higher Impedance to the Impedance of the Calibrated Load. These Tapers Were Used to Determine the Optimum Entrance Impedance to the Transition.
(Scale is 6-1/2")

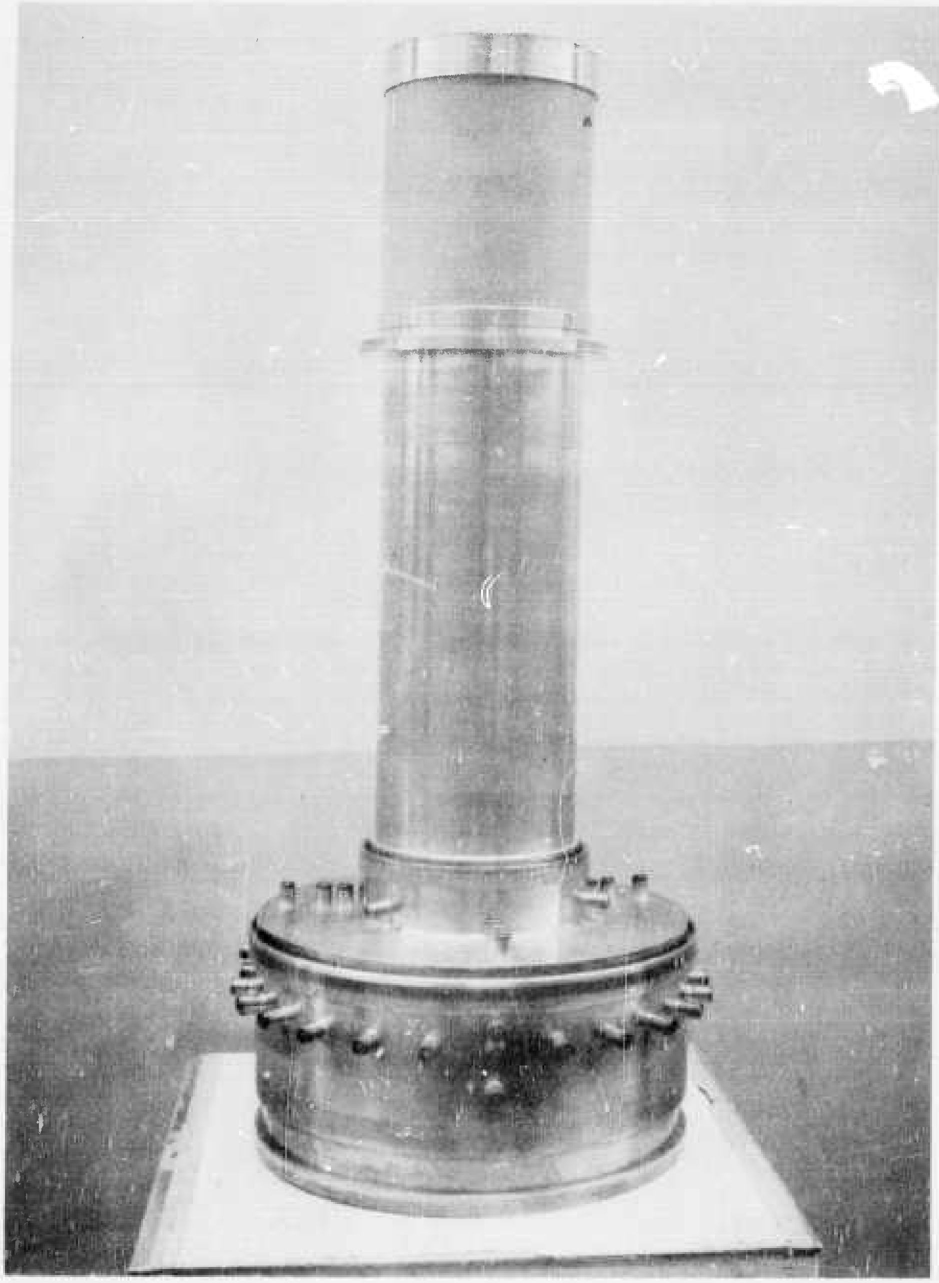

Figure 28 -- The Model A Coaxitron: An Interim Model with Single-Tuned Output Circuit Used to Establish Some of the Basic Design and Processing Concepts.

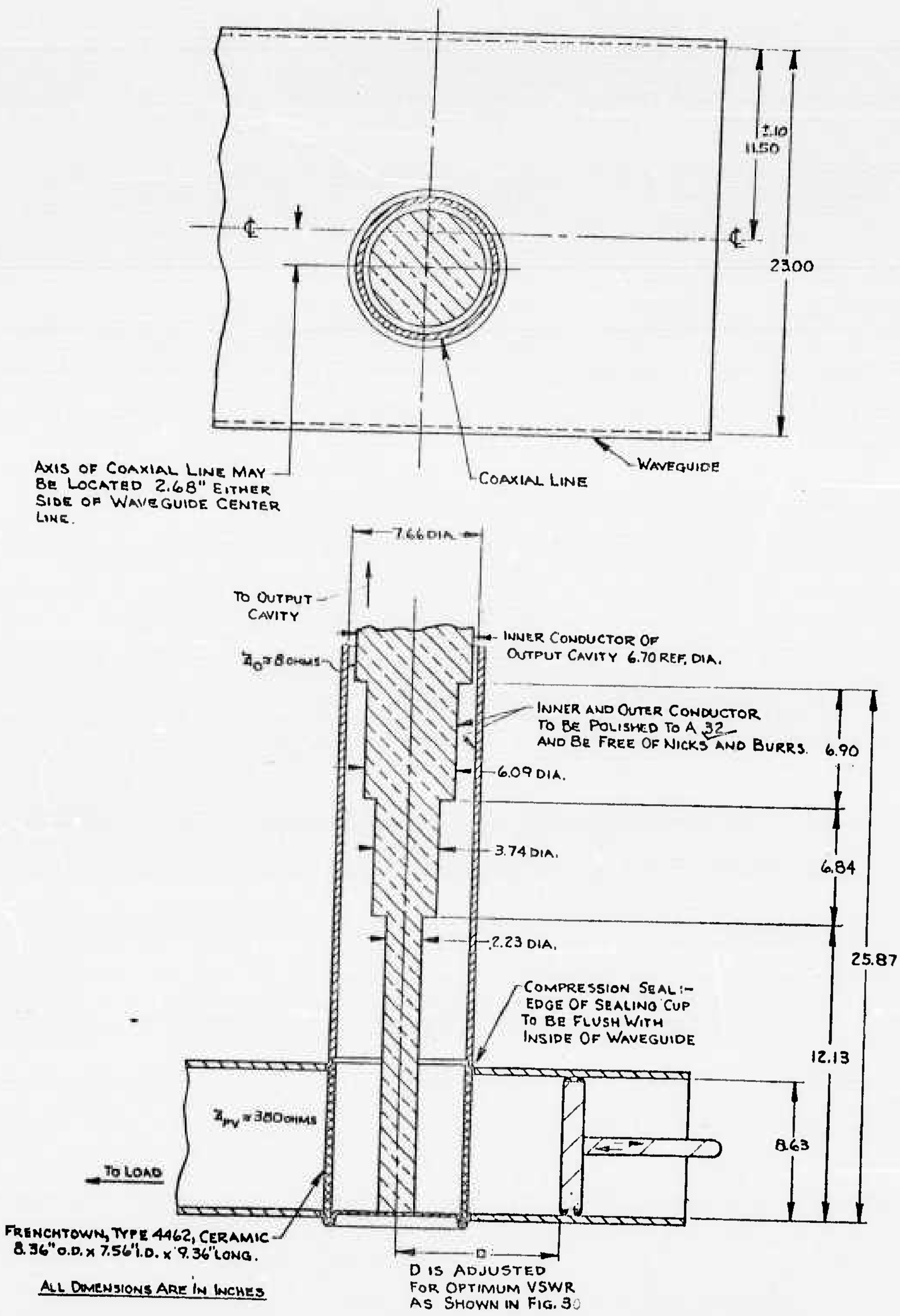

Figure 29 -- Dimensions of Interim Version, Model A Transition

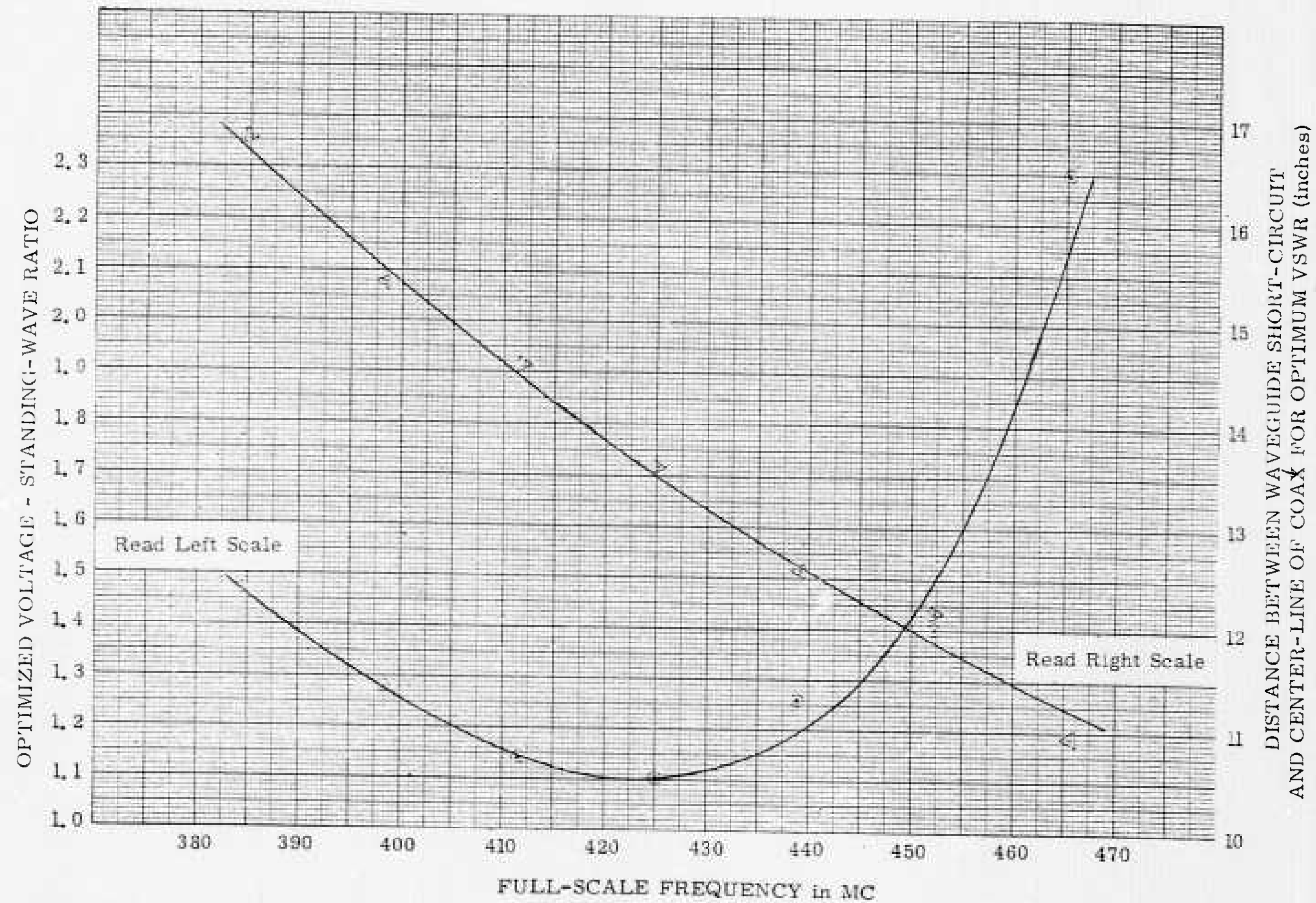

Figure 30 -- Interim Version, Model A Transition VSWR and Optimum Waveguide Short Position vs. Frequency

Tests and processing of the first Coaxitron were severly limited by an anode-to-grid short. The short was caused by a structural weakness in the anode coolant course which resulted in a bowing of the anode under coolant pressure. This structural defect has been corrected on the second experimental Coaxitron.

Programs for the Electronic Digital Computer

As referred to previously, much of the preliminary design work was done on an Electronic Digital Computer. Specifically, programs were set-up to evaluate the Coaxitron Output Circuit, the Coaxitron Active Input Circuit, and the Coaxitron Wide-Band Input Matching Transformer. These programs are on file at RCA, Princeton and would be extremely useful for further Coaxitron design at the present frequency band or at other frequencies.

SECTION VIII

SUGGESTED FUTURE COAXITRON DEVELOPMENT

The encouraging performance demonstrated during the provisional testing indicates that the Coaxitron amplifier is a high-power wide-band device capable of stable operation with good power gain and efficiency for several thousand hours of expected cathode emission life. The improved reliability and potential economy indicated by the provisional testing urges a continuation of the development program of this family of Coaxitrons.

Further Testing of Model B

Further aging and testing of the Model B Coaxitron at higher average power levels would be desirable in that it should yield valuable information pertaining to (1) design weaknesses not apparent at lower powers and (2) full power efficiency and power gain to be expected. In case the Coaxitron reaches a premature "ceiling" in operating level or becomes inoperative, the cause should be determined by a "post-mortem" examination and a suitable remedy incorporated in the design of a Model C Coaxitron. Pressurization of the accessory input circuit may be required for operation at higher power levels.

The equipment now available for the provisional testing provides rf drive pulses of 10 microseconds duration at a duty factor of 0.003 and at a peak power up to 160 kw. This is inadequate for testing to the minimum objectives of 25 microseconds and 0.01 duty factor stated in the technical objectives.

Furthermore, the plate supply used is not pulsed and is limited to about 15 kv dc, which is too low a voltage for the objective power output of 5 megawatts.

Equipment for High-Power Testing

Testing at higher average power under conditions more nearly satisfying the stated objectives would be possible by utilizing on a time sharing bases, the HPLF test equipment acquired on Contract AF30(602)-1396. The rf drive and pulsed plate voltage would be extended to the present Coaxitron exhaust and test position through quick changeover switches. A relatively simple adjustment should reduce the pulse length as low as 50 microseconds, which, at a repetition rate of 60, gives a duty factor of 0.003 (the value used in the above mentioned provisional tests). The 0.01 duty factor could be obtained with 150 microsecond pulses.

The nominal 200 kw output capability of the HPLF rf driver should provide excellent rf grid bombardment during processing with the pulse length set at 0.5 to 1 millisecond. The long-pulse drive could also be used to operate the Coaxitrons at their required average power output of 50 kw.

The full 5 megawatt peak power output may also be obtainable with the HPLF driver if the Coaxitron power gain stays up near the 30:1 observed in the tests at moderate power levels. However, a 10 db minimum objective would require a new rf driver capable of an output of 500 kw.

It is recommended that a complete government owned 1 megawatt driver be furnished for full power testing of Coaxitrons in order to insure an abundance of rf drive power at the objective 25 microsecond pulse length and 0.01 duty factor. A tunable magnetron type of driver would facilitate testing at a number of frequencies over a wide band. On the other hand, a wide-band amplifier-chain type driver would offer the additional possibility of complete "system" testing of a Coaxitron.

Modification of the HPLF modulator would also be required for operation at the higher repetition rate dictated by the 25 microsecond pulse length and 0.01 duty factor. This work involves the pulse generator and low level amplifier stages of the modulator.

In case the work load on the HPLF equipment becomes such that a time sharing arrangement is impractical, it would be technically feasible to use another large government owned test set acquired under Contract DA30-069-ORD-1955. The hard-tube modulator of this equipment is actually more suitable for Coaxitron testing than that in the HPLF set in that the pulse rate and length adjustment are more flexible. However, the rf driver operates at somewhat higher frequencies than the objective 385 to 465 Mc range and would hence require some circuit modification. The driver peak power output capability is only slightly higher than that of the HPLF, so that the new high-power driver discussed above would be desirable.

Coaxitron Design Procedure

The design effort would be directed toward (1) incorporating wideband integral input circuitry; (2) shifting the band-pass of the output circuitry slightly upward in frequency; (3) adding auxiliary cooling means inside the anode block to permit adequate anode-face heating during processing and (4) correcting any design limitations observed during further testing of the Model B Coaxitron.

Refinement of the tentative design for the integral input circuit would include (1) a determination of the electrical and physical parameters of the input slave-end circuit for the most uniform rf voltage distribution along the active cathode; (2) re-calculation of the parameters of the wide-band, high-ratio (approximately 250:1) input matching transformer for best VSWR on rf driver line; (3) a modified mechanical design of a new input structure consistent with the electrical requirements and capable of high temperature bakeout during evacuation. The calculations involved in the electrical design will be facilitated by electronic digital computer programs already developed. Some cold-test model work will also be needed as well as some experimental work to determine the mechanical feasibility of a few constructional details. Fabrication plans should call for sufficient parts and assemblies for two complete Coaxitrons ready for processing and test. This should give a reasonable expectation of at least one Coaxitron fulfilling the technical objectives.